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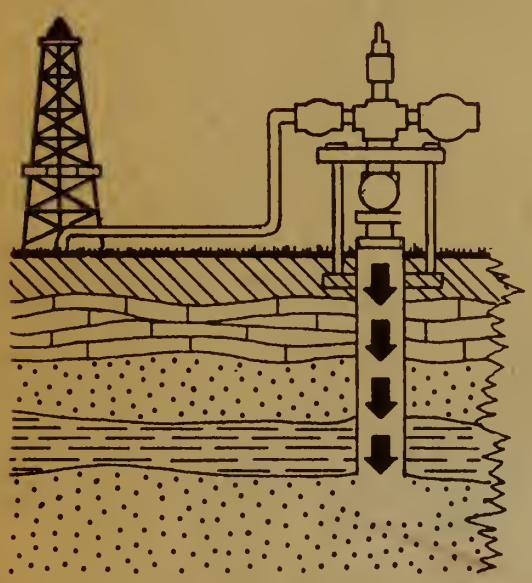

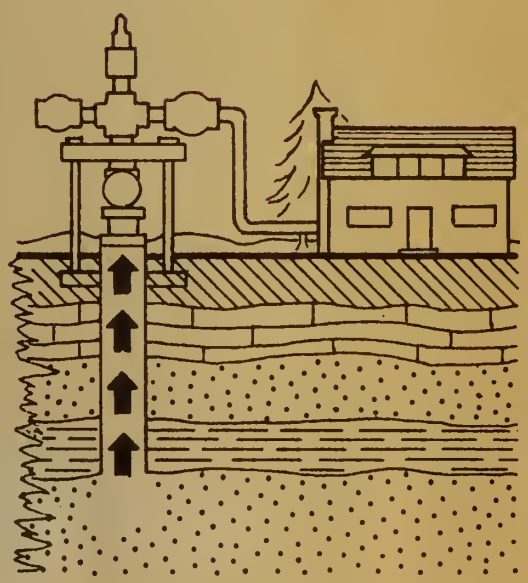

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UNDERGROUND STORAGE OF NATURAL GAS

IN THE

UNITED STATES

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RESEARCH COMMITTEE

INTERSTATE OIL COMPACT COMMISSION

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PREFACE

This study of the underground storage of natural gas by the Research Committee of the Interstate Oil Compact Commission was initiated in 1959 under the chairmanship of the late Dr. Charles Deiss. Much of the work of compiling the information was done under the chairmanship of Dr. J. M. Jewett in 1960, with the assistance of the five PAD district chairmen and co-chairmen. In 1961, under the chairmanship of Dr. Allen F. Agnew, Dr. William Lytle was appointed editor, and the manuscripts were assembled and prepared for publication by him. "Underground Storage of Natural Gas in the United States" was finished in January, 1962, under the chairmanship of Dr. John B. Patton.

Lawrence R. Alley
Executive Secretary

10/19/67

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UNDERGROUND STORAGE OF NATURAL GAS IN THE UNITED STATES

ALABAMA

Walter B. Jones
State Geologist

At the time of this report (August, 1960) there is no underground storage of natural gas in the State of Alabama, nor has there been any underground storage of natural gas in the past in this state. In 1956, the Southern Natural Gas Company drilled a proposed natural gas storage well located on the crest of one of the most prominent structural domes in the Paleozoic rocks of northwest Alabama. This well penetrated primarily Pennsylvanian shales and quartzites, all of which were found to lack permeability and porosity sufficient for storage purposes. The project was subsequently abandoned but still remains as the only serious attempt to establish an underground storage reservoir for natural gas in the entire state of Alabama.

The state is in dire need of adequate storage reservoirs. The problem is basically the same as that of finding new oil and/or gas reservoirs in the first place.

In the Paleozoic province of northwest Alabama where gas storage is an immediate need, it has been found that the rules of the oil game are reversed; necessary in this area is a basic understanding of what to expect among the interstices of hard rocks together with the ability to disdain the high-crested, symmetrical anticlines and the textbook domes.

As oil and gas development proceeds in south Alabama, new reservoirs of natural gas will in all likelihood be found and partially depleted; gas storage would subsequently be possible.

Although storage of natural gas in Alabama has not yet made its beginning, it is expected that development of storage reservoirs in porous rocks underlying geologically closed structures will eventually be successful and adequate for future needs in the state.

ARIZONA

D. A. Jerome
Executive Secretary
Oil and Gas Conservation Commission

Arizona does not have any underground gas storage projects. It is believed that an area near Holbrook which has a salt section would lend itself to this type of operation. Considerable preliminary work has been done by a gas company in this area in an effort to find a suitable gas storage reservoir.

ARKANSAS

R. A. Dumas, Member
Research Committee

The State of Arkansas has two oil and gas producing areas. The Northwest section of the state produces only dry gas, and the Southwest section contains the oil and condensate producing fields. The first gas field was discovered in 1901 in Northwest Arkansas. The first commercial oil production was discovered in 1920. The gas development in Northwest Arkansas has been slow due to a limited outlet for the produced gas. At the end of 1959, there were 380 wells capable of producing in the dry gas area with 59 of these wells shut in waiting for an outlet. During 1959, the gas production in Northwest Arkansas was 31,971 MMcf, which brought the cumulative production for the area to 343,589 MMcf. The oil and condensate fields of Southwest Arkansas had a total of 6,451 producing wells at the end of 1959. These wells produced 27,817,203 barrels of oil and condensate and 29,956 MMcf of gas during 1959. The cumulative production for this area at the end of 1959 was 1,081,281,386 barrels of oil and condensate and 1,025,381 MMcf of gas.

Gas storage has been undertaken only in the dry gas producing area of Northwest Arkansas. The first underground storage was started in 1942. At the present time, there are five underground gas storage projects in operation in that area. Four of these projects are in the immediate producing area and are using reservoirs that had been depleted or were nearing depletion. The fifth project is located in North Central Arkansas near the Missouri and Arkansas State lines. This project is utilizing an aquifer type reservoir by depressing the water level to obtain storage space.

There have been no major problems encountered in any of the storage operations that are using the depleted gas reservoirs. The Carrollton Dome Project, which is using the aquifer type reservoir, is in an early state of operation, but no problems have been encountered at this time.

A number of old gas producing reservoirs are nearing depletion and offer good possibilities for increase of volume of underground storage for long periods of time or for projects like those in operation today which are primarily designed to give a ready supply of gas during periods of peak demand.

The Arkansas Oil and Gas Commission requires that an application be filed for a gas storage system. The application must give the location of the intake well, or wells, and all producing oil and gas wells within one-half mile radius with a list of all landowners and operators within that one-half mile radius. The name, description, and depth of the formation to be used for storage must be provided, as well as information indicating that all other gas, oil, or fresh water bearing formations will be properly protected. A description of the gas, stating the kind, where obtained, and the estimated amounts to be injected daily, must be furnished with the application. Notice of the application must be given by the applicant to each operator within one-half mile radius of the intake well on or before the date the application is filed with the Commission. Objections to the proposed system must be made within ten days of the date the application is filed.

In case objections are received or the Commission deems it necessary, a hearing shall be had to determine whether or not the system should be approved. If the system is approved, the operator must maintain accurate record of the gas injected, and such information shall be made available to the Commission. Notice of commencement of the system or discontinuation of the system shall be furnished the Commission.

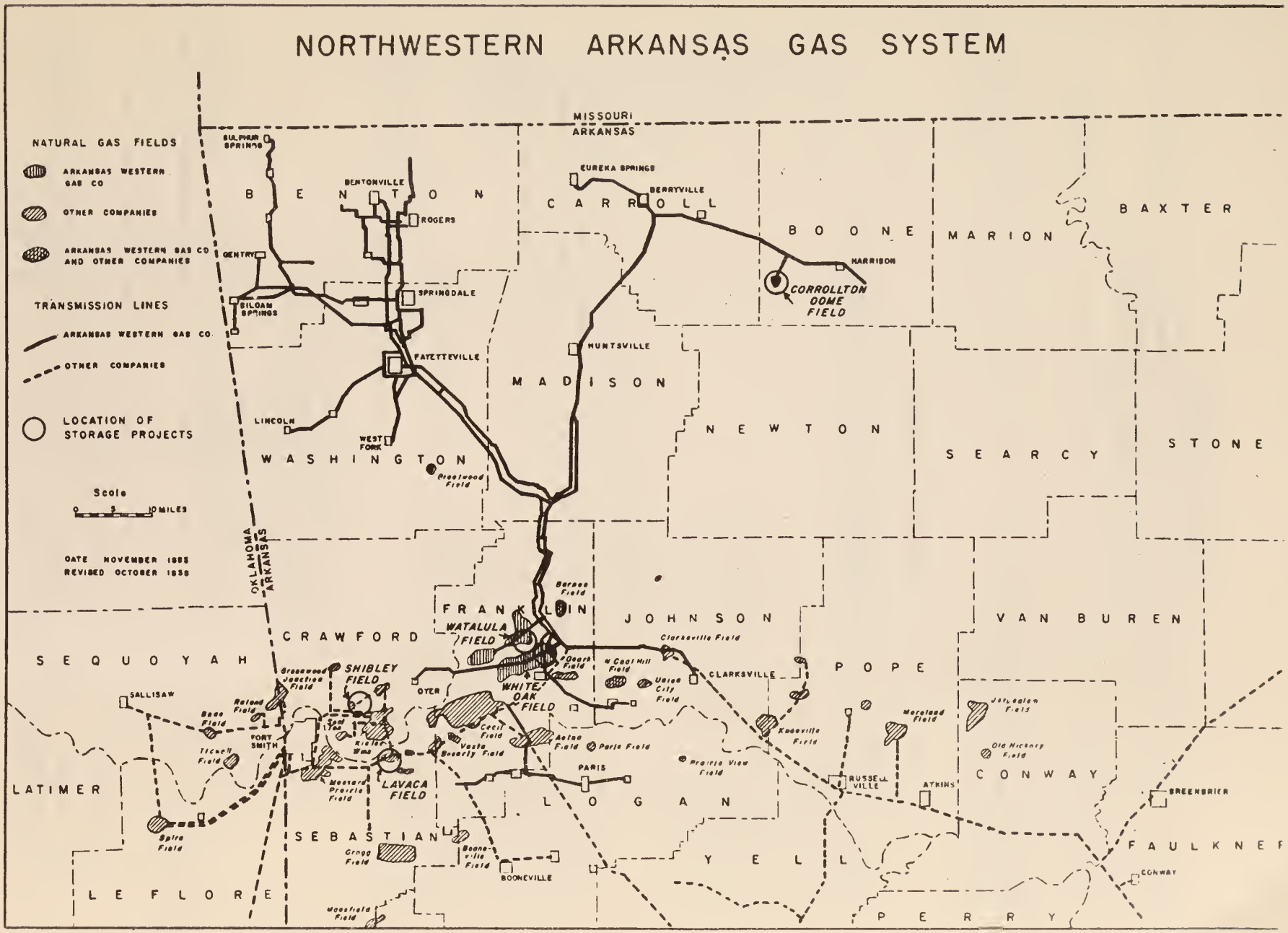
Data for each storage project (see figure 1) is listed below:

LaVaca Storage Project

Operator: Stephens Production Company, Ft. Smith, Arkansas.
Location: Sections 21, 22, 27, 28, Township 8 North, Range 30 West, Sebastian County.
Geology: Anticline, A sand of the Atoka Formation, Pennsylvanian Age.
Depth: 2,824 feet.
Average Sand Thickness: 20 feet.
Area: 820 acres.
Capacity of Reservoir: 4 billion cubic feet.
Injection Rate: 5 million cubic feet per day.
Injection Pressure: 250 psi.
Deliverability: 12 million cubic feet per day.
Injection started: June, 1942.

Shibley Northwest Storage Project

Operator: Stephens Production Company, Ft. Smith, Arkansas.
Location: Section 15, Township 9 North, Range 31 West, Sebastian County.
Geology: Faulted anticline, a sand of the Atoka Formation, Pennsylvanian Age.
Depth: 1,235 feet.
Average Sand Thickness: 13 feet.
Area: 320 acres.
Capacity of Reservoir: 1.2 billion cubic feet.
Injection Rate: 700 thousand cubic feet per day.
Injection Pressure: 240 psi.
Deliverability: 3 million cubic feet per day.
Inection started: March, 1949.


NORTHWESTERN ARKANSAS GAS SYSTEM
NATURAL GAS FIELDS
ARKANSAS WESTERN GAS CO
OTHER COMPANIES
ARKANSAS WESTERN GAS CO AND OTHER COMPANIES
TRANSMISSION LINES
ARKANSAS WESTERN GAS CO
OTHER COMPANIES
LOCATION OF STORAGE PROJECTS
Scale
0 5 10 MILES
DATE NOVEMBER 1955
REVISED OCTOBER 1958
MISSOURI
ARKANSAS
OKLAHOMA
ARKANSAS
BENTON
CARROLL
BOONE
MARION
BAXTER
MADISON
NEWTON
SEARCY
STONE
WASHINGTON
FRANKLIN
JOHNSON
VAN BUREN
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WEST FORK
EUREKA SPRINGS
BERRYVILLE
HARRISON
CORROLLTON DOME FIELD
HUNTSVILLE
Brentwood Field
Barnes Field
WATALULA FIELD
WHITE OAK FIELD
SHIBLEY FIELD
LAVACA FIELD
OTER
Clarksville Field
CLARKSVILLE
N Coal Hill Field
Union City Field
Kuoneville Field
Moreland Field
Jerusalem Field
Old Hickory Field
Grassmere Junction Field
Roland Field
Bone Field
FORT SMITH
Tickell Field
Spire Field
Mossard Prairie Field
Cecil Field
Vesta Beverly Field
Aetna Field
Paris Field
Prairie View Field
PARIS
RUSSELLVILLE
ATKINS
BREENBRIER
CONWAY
Grogg Field
Booneville Field
BOONEVILLE
Moosfield Field

Figure 1.

Watalula Storage Project

Operator: Arkansas Western Gas Company, Fayetteville, Arkansas.
Location: Section 4, Township 10 North, Range 27 West, Franklin County.
Geology: Faulted anticline, a sand of the Atoka Formation, Pennsylvanian Age.
Depth: 2,688 feet.
Average Sand Thickness: 19 feet.
Area: 640 acres.
Capacity of Reservoir: 1 billion cubic feet.
Injection Rate: 1 million cubic feet per day.
Injection Pressure: 600 to 800 psi.
Deliverability: 6 million cubic feet per day.
Injection Started: April, 1956.

White Oak Storage Project

Operator: Arkansas Western Gas Company, Fayetteville, Arkansas.
Location: Section 23, 24, Township 10 North, Range 27 West, Franklin County.
Geology: Anticline, a sand of the Atoka Formation, Pennsylvanian Age.
Depth: 1,320 feet.
Average Sand Thickness: 25 feet.
Area: 400 acres.
Capacity of Reservoir: 7 billion cubic feet.
Injection Rate: 10 million cubic feet per day.
Injection Pressure: 380 to 590 psi.
Deliverability: 10 million cubic feet per day.
Injection Started: April, 1958.

Carrollton Dome Storage Project

Operator: Arkansas Western Gas Company, Fayetteville, Arkansas.
Location: Sections 13, 18, 19, 24, Township 18 North, Range 21 and 22 West, Boone County.
Geology: Faulted elongated dome, Gunter Sand of the Arbuckle Formation, Ordovician Age.
Depth: 2,228 feet.
Average Sand Thickness: Water level to be depressed approximately 250 feet for storage space.
Area: 964 acres.
Capacity of Reservoir: 9 billion cubic feet.
Injection Rate: 4 million cubic feet per day.
Injection Pressure: 772 psi (after water is depressed to desired level).
Deliverability: 8 million cubic feet per day.
Injection Started: July, 1959.

COLORADO

William R. Smith
Senior Petroleum Engineer
Oil and Gas Conservation Commission

General Remarks

To date there have been only two gas storage projects in Colorado. These projects will be more fully discussed later; however, it is of interest to note, at this point, that they vary in at least two significant ways:

1. The Rangely-Entrada Project is on the western slope in a sparsely populated area, and the Leyden Project is on the eastern slope in a densely populated area.

2. One, the Rangely Project, is primarily a project designed to study possible storage of excess produced gas in a reservoir different from the producing reservoir, and the other, the Leyden Project, is primarily designed for peak load control of a marketing area.

Previous studies have been made of the Fort Collins, Black Hollow, and Wellington fields; however, at this time, results have been fruitless.

Gas Production in Colorado

A map published by the United States Geological Survey shows gas fields and pipelines as of March, 1958. No appreciable change has occurred since that time.

Total gas production for the year 1959, as well as cumulative gas production through 1959, and gas sales are shown below by counties. It should be noted that the figures include all gas produced, both from oil and gas fields, for counties with gas sales only.

Table 1 - Gas Production in Colorado 1959

County	Gas Sold (MMcf)	Gas Production (MMcf)	Cumulative Gas Production (MMcf)
Adams	1,294	1,786	7,340
Baca	439	439	2,016
Bent	6	10	97
Garfield	762	781	4,415
Jackson	273	60,036*	333,336*
Kiowa	4	4	6
La Plata	26,861	27,667	154,099
Las Animas	82*	82*	2,061*#
Logan	9,900	12,128	100,895
Mesa	694	797	4,081
Moffat	9,775	10,477	160,793
Montezuma	94*	232	1,106
Montrose	14	14	14
Morgan	12,387	14,299	57,520
Rio Blanco	7,002	59,856	395,409
Sedgwick	2	2	2
Washington	2,419	3,817	24,514
Weld	1,079	2,013	11,187

(*) Includes CO_2
(#) Includes Helium
Note: Only counties which have gas sales are shown.

Stratigraphy and Structural Geology in Colorado with Reference to Gas Storage

Colorado, located as it is in the Rocky Mountains, contains several geologic provinces.

Gas Storage Projects in Colorado

1. Rangely-Entrada

   a. Location - Township 2 North, Range 102 West, Rio Blanco County.

   b. Geology
      (1) Entrada Formation of Jurassic Age.
      (2) Anticlinal Structure.

   c. Injection Data
      Initial Injection - March 14, 1956
      Date of last injection - October 1, 1957

Cumulative injection - 4,578,868 Mcf (as of January 1, 1960)
Injection rates, variable to a maximum of approximately 23,800 Mcfd.

d. Delivery
To date, no significant withdrawals have been made.

2. Leyden

a. Location - Township 2 South, Range 70 West, Jefferson County.

b. Geology
(1) Laramie Formation of Upper Cretaceous Age.
(2) An old coal mine from which approximately six million tons of coal had been removed.

c. Injection Data
Initial Injection - about July 1, 1959 (test program - air).
September, 1959 (test program - gas).
Cumulative Injection (as of February 19, 1960)
140,000 Mcf at 90 psig, and
60,000 Mcf at 65 psig.

d. Delivery equipment
1,725 h.p. of compressor facilities capable of withdrawing 10,000 Mcfd
To date no withdrawals have been made.

Possibilities of Expansion

At the present time, both of the storage projects in Colorado are in a test status, and any comment on expansion would be premature.

Regulations Affecting Storage Projects

Appendix A is a section of the Colorado Statutes which are self-explanatory.

Conclusions

As indicated above, there are only two projects for gas storage currently operative in the state. Since neither of these projects has redelivered gas, other than test volumes, any comment on their future development would be premature.

With the rapid growth on the eastern slope, in the Colorado Springs-Denver-Fort Collins areas, which are removed from gas producing areas by several miles, domestic natural gas requirements become ever more demanding with peak loads due to cold snaps, an ever more serious problem to the gas suppliers. As a result, increased activity and interest should be noted in the next few years.

APPENDIX A

Article 9
Underground Storage

100-9-1 Definitions.
100-9-2 Legislative declaration.
100-9-3 Condemnation - public use.
100-9-4 Application to commission - order.
100-9-5 Hearing - notice - review.
100-9-6 Petition to district court - procedure.
100-9-7 Property rights.

"100-9-1. Definitions. - (1) 'Underground reservoir' shall mean any sub-surface sand, stratum, or formation suitable for the injection and storage of natural gas therein and the withdrawal of natural gas therefrom.

(2) 'Underground storage' shall mean the right to inject and store natural gas within and to withdraw natural gas from an underground reservoir.

(3) 'Natural gas' shall mean gas which has been produced from the earth in its original state or such gas after the same has been processed or treated.

(4) 'Natural gas public utility' shall mean any person, partnership, corporation, or association authorized to do business in this state as a public utility and engaged in the business of transporting, distributing, or storing natural gas within this state for ultimate public use or consumption.

(5) 'Commission' shall mean the oil and gas conservation commission of the state of Colorado.

Source: L. 53, p. 439, 1.

"100-9-2. Legislative declaration. - Underground storage of natural gas is hereby found and declared to be in the public interest, because it will promote the conservation of natural gas, make natural gas more readily available to the domestic, commercial, and industrial consumers of this state, and permit the building of natural gas reserves and orderly withdrawal thereof in periods of peak demand.

Source: L. 53, p. 440, 2.

"100-9-3. Condemnation - public use. - Any natural gas public utility which is engaged in the distribution, transportation, or storage of natural gas, which gas, in whole or in part, is intended for ultimate distribution to the public, shall have the right to enter upon, take or use property or any interest therein which is necessary for the injection, storage, and withdrawal of natural gas in the manner provided for by this article and by the eminent domain law of the state of Colorado, all of which property to be used is hereby recognized and declared to be devoted to public use.

Source: L. 53, p. 440, 3.

"100-9-4. Application to commission - order. - Before the right of condemnation may be exercised for the acquisition of property or any interest therein for underground storage of natural gas, said natural gas public utility shall make application to the oil and gas conservation commission of the state of Colorado, hereinafter referred to in this article as the 'commission,' for an order approving the proposed storage project. No such order shall be issued by the commission unless it shall be based upon substantial evidence and shall contain findings that the underground storage of natural gas in the land sought to be condemned is in the public interest and welfare, and that the storage reservoir is suitable and practicable, and that the formation or formations sought to be condemned are nonproductive of oil or gas in commercial quantities under either primary or secondary recovery methods.

Source: L. 53, p. 440, 4.

"100-9-5. Hearing - notice - review. - Upon the filing of the application as specified in section 100-9-4, the commission shall set a date for hearing and give notice thereof as for proceedings in rem in accordance with the rules of civil procedure of the state of Colorado and shall conduct said hearing in the manner provided for in sections 100-6-7 to 100-6-10.

Review of or relief from such order shall be as provided for in sections 100-6-11 to 100-6-14.

Source: L. 53, p. 440, 5.

"100-9-6. Petition to district court - procedure. - Any natural gas public utility having first obtained an order from the commission which has become final, desiring to exercise the right of eminent domain for the purpose of acquiring property for the underground storage of natural gas, shall do so in the manner provided in this article. Such natural gas public utility shall present to the district court of the county wherein the land or some portion thereof is situated a petition setting forth the purpose for which the property is sought to be acquired, a description of the property sought to be appropriated, and the names of the owners thereof as shown by the records of such county. The petitioner shall file the order of the commission as a part of its petition, and no decree or rule by the court granting said petition shall be entered without such order having been filed therewith. The court shall examine said petition and determine whether the petitioner has the power of eminent domain and whether said property is necessary for its lawful purposes, and if found in the affirmative such findings shall be entered in the record. All proceedings under this section shall follow the procedure then in force and effect pertaining to eminent domain.

Source: L. 53, p. 440, 6.

"100-9-7. Property rights. - All natural gas in said underground reservoir and the rights reasonably necessary for the injection and storage in and withdrawal from said underground reservoir of said natural gas, as defined and limited by the decree of the district court, shall be the property of said natural gas public utility. In no event shall such gas be subject to the right of the owner of the surface of said lands or of any mineral interest therein or of any person other than the public utility, its successors or assigns, to produce, take, reduce to possession, or otherwise interfere with or exercise any control thereover. The right of condemnation hereby granted shall be without prejudice to the rights of the owner of said land or of other rights and interests therein to drill or bore through the underground stratum or formation so appropriated in such manner as to comply with orders, rules and regulations of the commission issued for the purpose of protecting underground storage, strata, or formations against pollution or against the escape of natural gas therefrom and shall be without prejudice to the rights of the owner of said lands or other rights or interests therein as to all other uses thereof. The additional cost of complying with such regulations or orders in order to protect the storage shall be paid by the public utility.

Source: L. 53, p. 441, 7."

DELAWARE

John K. Adams, University of Delaware
Robert R. Jordan, Delaware Geological Survey

Introduction

Considerable quantities of natural gas are used in Delaware. However, there are no facilities for the storage of large quantities of gas within the state. All the gas is "piped in" and distributed by the local public utility companies. These companies are interested in the possibilities for the underground storage of natural gas, but there are no obvious underground reservoirs such as depleted oil or gas fields.

About 95% of Delaware is situated in the Atlantic Coastal Plain Physiographic Province. The unconsolidated sediments of Mesozoic and Cenozoic age, which make up this province, dip gently toward the southeast and thicken "down dip." Possibilities for the storage of natural gas do exist within the Delaware Coastal Plain. However, the stratigraphy and structure are not understood in enough detail to make any specific recommendations.

General Geology of Delaware

General Statement

The State of Delaware extends into two physiographic provinces - the Piedmont and the Atlantic Coastal Plain. A small portion of the state, north of a line drawn between Wilmington and Newark, lies in the Appalachian Piedmont Province; the rest of the state is in the Atlantic Coastal Plain.

The Piedmont is characterized by rolling hills which are developed on the Precambrian or Paleozoic crystalline rocks. The regional structures in this area trend northeast. A weathered zone averaging 35 feet in thickness mantles the area. The rocks of the Piedmont extend to the southeast and form the basement complex which underlies the Coastal Plain formations.

The Coastal Plain portion of the state has flatter topography. The rocks in the Coastal Plain are predominantly unconsolidated sediments of Mesozoic and Cenozoic age. They strike northeast and form a wedge-shaped mass which feathers out at the Fall Line and thickens to approximately 8,000 feet in the southeastern part of the state. Nearly all of the Coastal Plain is covered by a relatively thin mantle of Pleistocene sediments.

The boundary between the Coastal Plain and the Piedmont is termed the Fall Line. Along this line the topography changes from hilly to flat, and the rocks change from crystallines to sediments. The streams which cross this zone often develop rapids or small waterfalls due to the difference in the ease of erosion of the two types of rocks.

Piedmont Province

Glenarm Series

The oldest rock units known in Delaware are the Cockeysville Marble and the Wissahickon Schist. Both of these formations belong to the Glenarm series of metasediments.

The Cockeysville Marble underlies two small areas in the Delaware Piedmont (see geologic map, figure 2). In outcrop the rock is a dense, white to light gray, coarsely crystalline limestone; it is sometimes dolomitic. Areas in which the Cockeysville is exposed are interpreted as unroofed anticlines. At an abandoned quarry site near Pleasant Hill, the Cockeysville is tightly folded. The Cockeysville has been quarried for lime in the past.

In Delaware, the Wissahickon Schist directly overlies the Cockeysville Marble. The Wissahickon is highly variable mica schist which contains several small bodies of amphibolites as well as several generations of pegmatites. At the Wooddale Quarry, a small mass of granite occurs in the Wissahickon, and there is a small body of serpentine near Mount Cuba.

The age of the Cockeysville Marble and the Wissahickon Schist is open to question. Although they were first considered to be Precambrian (Bascom & Miller, 1920), it has been suggested more recently (Watson, 1957) that they may be equivalent to the less highly metamorphosed lower Paleozoic rocks of nearby Pennsylvania. They have probably been subjected to several regional deformations culmintating with the Appalachian Revolution.

Wilmington Complex

The eastern and southeastern portion of the Delaware Piedmont is underlain by rocks of igneous origin. The various rocks of this area are known collectively as the Wilmington Complex. The Wilmington Complex comprises roughly one-half of the Delaware Piedmont. Ward (1959) has divided the complex into several rock units and describes each in detail.

The largest part of the complex consists of a banded gneiss which occupies most of the eastern part of the area. Near the center of the banded gneiss, north of Wilmington, an area of about four square miles is underlain by the Arden granite. According to Ward (1959, p. 1438) the Arden granite "... in some places has the composition of a true granite." It appears to be intrusive into the banded gneiss. Toward the southwest the banded gneiss grades into amphibolites of varying compositions. A small stock of gabbro intrudes the banded gneiss at Bringhurst, north of Wilmington. Similar stocks form Iron and Chestnut Hill near Newark, Delaware, and Grays Hill near Elkton, Maryland. The relationship of the last three masses mentioned is unknown. They are inliers, and each is surrounded by Cretaceous and Pleistocene sediments.

A small area west of Newark is underlain by the Port Deposit granodiorite. The Port Deposit is an extensive unit in nearby Maryland. Near Newark it is intrusive into the amphibolites of the Wilmington Complex.

The main structural features of the complex parallel those of the Cockeysville Marble and Wissahickon Schist. This may indicate simultaneous deformation. The Arden granite and the gabbro stocks probably intruded the older rocks (banded gneiss and amphibolites) at a time very late in the regional metamorphism, for they are not deformed. Ward (1959, p. 1456) suggests that the Port Deposit granodiorite "... may be in part older and in part younger than..." the gabbro.

Coastal Plain

Rocks similar to those of the Piedmont province are known to extend far beyond the Fall Line and to make up the basement complex upon which the homoclinal Coastal Plain sediments are deposited. The homocline dips gently to the southeast, toward the Atlantic Ocean. Each unit dips slightly less than the underlying unit. The individual units thicken down dip. The maximum total thickness reaches about 8,000 feet in the southeastern corner of the state. Except for the marine Cretaceous outcrops in banks of the Chesapeake and Delaware Canal and the various sand and gravel pits in the Pleistocene, the Coastal

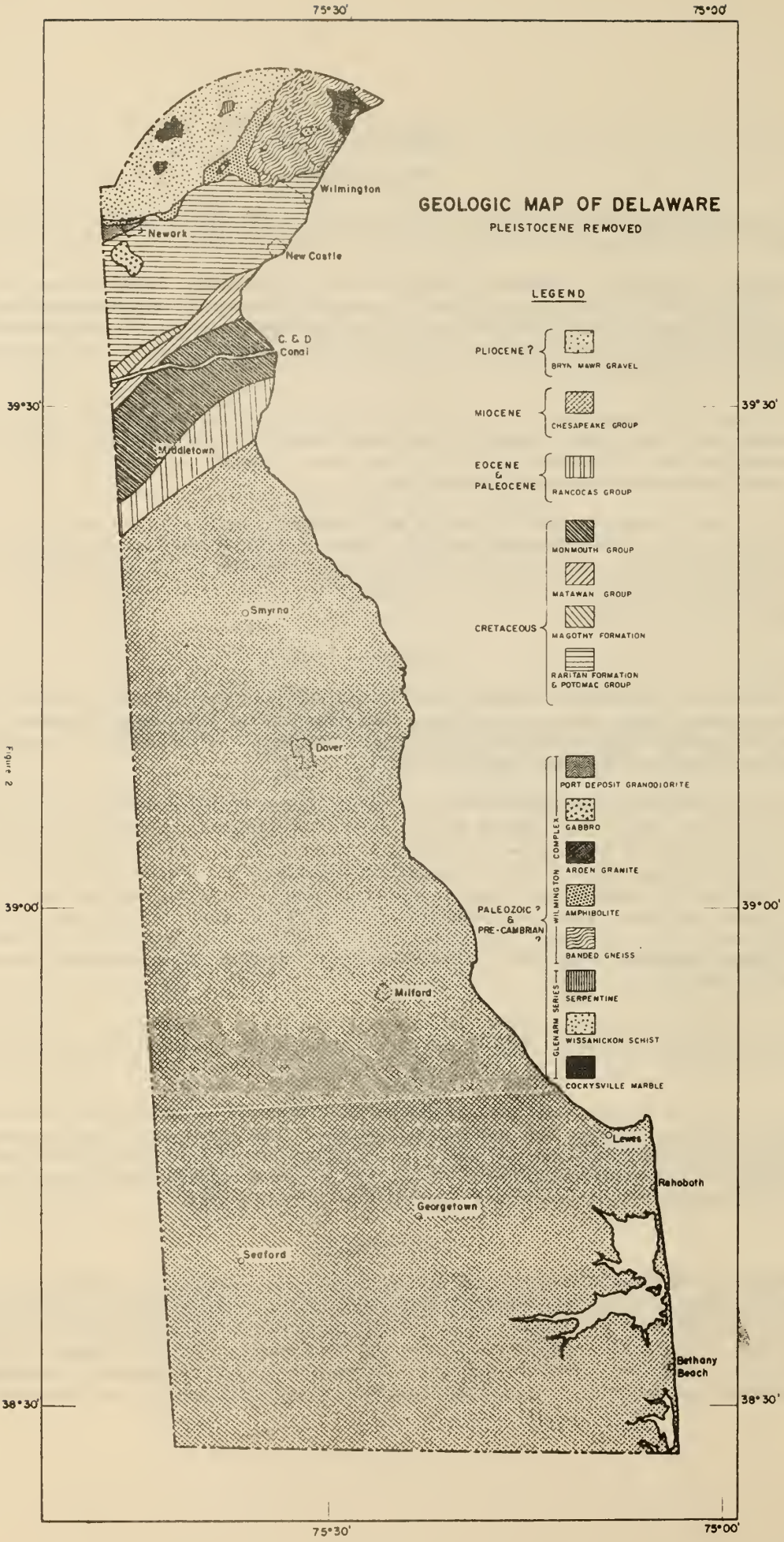
GEOLOGIC MAP OF DELAWARE
PLEISTOCENE REMOVED
LEGEND
PLIOCENE ?
BRYN MAWR GRAVEL
MIOCENE
CHESAPEAKE GROUP
EOCENE & PALEOCENE
RANCOCAS GROUP
CRETACEOUS
MONMOUTH GROUP
MATAWAN GROUP
MAGOTHY FORMATION
RARITAN FORMATION & POTOMAC GROUP
PALEOZOIC ? & PRE-CAMBRIAN ?
WILMINGTON COMPLEX
PORT DEPOSIT GRANODIORITE
GABBRO
AROEN GRANITE
AMPHIBOLITE
BANDED GNEISS
GLENARM SERIES
SERPENTINE
WISSAHICKON SCHIST
COCKYSVILLE MARBLE
Wilmington
Newark
New Castle
C. & D Canal
Middletown
Smyrna
Dover
Milford
Lewes
Rehoboth
Georgetown
Seaford
Bethany Beach
75°30'
75°00'
39°30'
39°00'
38°30'

Figure 2

Plain sediments are very poorly exposed in Delaware. Facies changes are common between outcrop and down dip wells.

Triassic System

Rocks of Triassic age are not definitely known in Delaware; however, they are reported from deep oil test wells in Maryland not far south of the Delaware state line. Anderson (1948) states that in both the Ohio Oil Company's Hammond No. 1 well, near Salisbury, Maryland, and the Socony-Vacuum Oil Company's Bethards No. 1 well, near Berlin, Maryland, strata occur which are referable to the Newark Series of Triassic age on the basis of their lithology. In the Bethards well, the Triassic consists of indurated conglomerate, red and green sandstone, reddish-brown and greenish-gray shales, and sandy shales. Anderson places the top of the Triassic System in the Bethards well at approximately 6,566 feet (30' el.). He recognizes 585 feet of Triassic sediment from the well. In the Hammond well, the Triassic is 135 feet thick and the top of the unit is at a depth of 5,363 feet (70' el.). The relationship of the Triassic sediments to the underlying basement or to the overlying Cretaceous sediments is unknown.

The proximity of such a thickness of Triassic sediments to Delaware suggests that rocks of Triassic age may occur at similar depths in southeastern Delaware.

Cretaceous System

The sediments of the Cretaceous System of Delaware may be referred to as older non-marine section and to a younger, marine section. The non-marine Cretaceous consists of the Lower Cretaceous Patuxent and Patapsco formations (Potomac group) and the upper Cretaceous Raritan Formation according to Miller (Bascom and Miller, 1920). Groot (1955, pp. 25-26) found that the Patuxent, Patapsco, and Raritan formations cannot be reliably differentiated in the field in Delaware. Various authors have assigned different ages within the Cretaceous to the non-marine deposits. Recent palynological studies by Groot and Penny (1960) have led to the conclusion that the non-marine sediments range from Lower Cretaceous to lower Upper Cretaceous age. The fact that the greater thickness of the non-marine section belongs to the Lower Cretaceous is shown by samples from wells near Delaware City, Delaware, and Salisbury, Maryland.

The sediments are variegated clays and sandy clays with lenses of fine to coarse sand. Some of the sands may be channel deposits. The outcrop area, which is mantled by a thin layer of Pleistocene sand, occupies a band about 10 miles wide adjacent to the Fall Line. The non-marine Cretaceous sediments are reported by Anderson (1948, pp. 92-94) to reach a thickness of about 5,230 feet in a well 100 miles down dip near Ocean City, Maryland. The non-marine Cretaceous sediments dip southeast about 30 feet per mile.

The overlying Magothy Formation is thought to represent the transitional phase between the deposition of the non-marine and marine Cretaceous sediments. Where it is exposed in the banks of the Chesapeake and Delaware Canal, the Magothy consists of black, lignitic clays, brown silty sands, and fine to very coarse, cross-bedded, clean white sands. It reaches a thickness of about 30 feet in the Canal outcrops. The Magothy is recognized by Rasmussen, Groot, and Depman (1958) as occupying the interval from 1,283 feet to 1,385 feet in a cored well at Dover Air Force Base near Dover, Delaware.

The Merchantville is the oldest of the truly marine Cretaceous formations in Delaware. The Merchantville together with the overlying Wenonah Formation constitute the Matawan Group. In the exposures in the Chesapeake and Delaware Canal the Merchantville is a dark blue to black, poorly sorted, glauconitic and micaceous, silty, quartz sand. The contact between the Merchantville and the Wenonah is gradational. The Wenonah is a brown to gray, fine, well sorted quartz sand with small amounts of mica and glauconite. A characteristic of the Wenonah Formation is the presence of numerous tubes of uncertain origin which have been called Halymenites major Lesquereux. In outcrop the Merchantville is about 30 feet thick, and the Wenonah is about 10 feet thick. Both formations appear to become somewhat calcareous and more glauconitic down dip.

Above the Matawan Group are the sediments of the Monmouth Group. Groot, Organist, and Richards (1954) have described two formations of the Monmouth group from the banks of the Chesapeake and Delaware Canal. The Mount Laurel and Navesink formations, named from exposures in New Jersey, could not be differentiated in Delaware and are treated as one unit, the Mount Laurel-Navesink Formation.

The Mount Laurel-Navesink, in outcrop, is a dark-green, fine, poorly sorted, highly glauconitic, silty, quartz sand. It is often highly fossiliferous. It grades upward into the Red Bank and appears to grade downward into the Wenonah. The Mount Laurel-Navesink is about 10 feet thick at the canal. The Red Bank Formation, which overlies the Mount Laurel-Navesink, is a reddish-brown, fine to medium, fairly well sorted quartz sand.

In the Dover Air Force Base well, 35 miles down dip from the outcrop, the interval assigned to the Monmouth Group consists of gray, glauconitic silts and clays. In this well, the top of the Monmouth Group, which is also the top of the Cretaceous System, occurs at 980 feet.

Tertiary System

Paleocene Series. Rocks of Paleocene age are not definitely known to crop out in Delaware. Paleocene sediments are, however, present in the subsurface. The well at Dover Air Force Base penetrated more than 100 feet of gray, glauconitic silts and clays belonging to the Paleocene. This section is believed to be equivalent in age to the Hornerstown Formation of New Jersey and to the Brightseat Formation and a part of the Aquia Formation of Maryland.

Eocene Series. Greensands of probably Eocene age crop out in southern New Castle County. These sediments are referred to the Rancocas Formation on the 1906 geologic map (Miller 1906). Paleontological evidence, however, is limited to the subsurface; work currently in progress at the Delaware Geological Survey suggests that a rather complex Eocene section is present. The lower part of the Eocene section in the Dover Air Force Base well consists of gray, glauconitic silts and clays. Above the silts and clays, the greensands reach a thickness of 250 feet. At Dover, the top of the greensand occurs at -310 feet (sea level datum).

Miocene Series. The Miocene Series is known mainly from water wells in central Kent County. It is described by Marine and Rasmussen (1954, p. 45) as consisting of three units of clay separated by two units of sand. The Miocene is almost entirely unknown farther down dip where stratigraphically higher units, chiefly silts and fine sands, are added to the section. The Miocene deposits constitute the Chesapeake Group (Clark, Mathews and Berry, 1918, p. 218).

Pliocene (?) Series. Gravelly sand which occurs in thin patches on the uplands north of Wilmington and in nearby Pennsylvania has been called the Bryn Mawr gravel. No direct evidence for the age of the Bryn Mawr gravel exists. It is referred to as Pliocene (?) by Bascom and Stose (1932).

Quaternary System

Pleistocene Series. The Pleistocene deposits of Delaware consist of tan sands and gravels with some dark, clayey silts and silty clays. These deposits mantle the entire Delaware Coastal Plain. In the northern portion of the state they are coarser than in the south and often take the form of stream channel deposits. In southern Delaware, the Pleistocene sediments reach a thickness of 100 to 150 feet.

Possibilities for Natural Gas Storage in Delaware

General Statement

Delaware does not produce, nor has it produced any natural gas or natural petroleum products of commercial value. At the present time, the state does not store any natural gas underground, although most of the gas marketed in the state is natural gas. Delaware is experiencing a period of economic expansion and population growth. If this expansion and growth continues, heavier demands will be placed upon the public utilities which supply natural gas. The suppliers of natural gas must concern themselves with 'peak days,' that is, very cold days when the heaviest demands are made by the consumer. If the situation should ever arise that much heavier demands were made by the domestic consumer, the suppliers might find that they would have to divert the gas being used by the industrial customer to the domestic consumer with a resulting financial loss to the industrial customer. This situation is, of course highly undesirable, and the only solution is that the gas supplier increase the gas supply on peak days. In order to do this, the suppliers must be able to store larger quantities of gas or produce their own gas.

One of the desirable characteristics for gas storage is a location close to the market area so that the gas may be delivered quickly. This is an advantage which the gas suppliers in Delaware do not enjoy.

All of the natural gas is piped into the state by the Transcontinental Gas Pipe Line Corporation of Houston, Texas. It would be highly desirable to develop within the state areas which would serve as storage reservoirs for natural gas. At present there is no known structure suitable for the storage of natural gas; however, more detailed study of the stratigraphy of the state and more research on rock units which may be suitable for gas storage could lead to the development of reservoir sites.

The desirable and/or necessary characteristics for a gas storage field include: location close to the market area; well defined limits of closure so that the gas does not migrate; high total capacity and suitable confining pressure or strength of the enclosing rock unit; and a suitable method for injecting and withdrawing the gas quickly. Some of the formations in the Delaware Coastal Plain have, or could develop, all of the features except the well defined limits of closure. This is not to say that there are no suitable structures in the Delaware Coastal Plain, only that structures with this potential have not been discovered or developed.

Precambrian and Paleozoic Rocks

The Precambrian and Paleozoic crystallines of Delaware are not very suitable for the storage of natural gas. Although some of the foliate rocks may have suitable porosity and volume to hold considerable quantities, it is doubtful that there are any traps which would retain the natural gas. An important role which the crystallines may play in providing suitable areas for the storage of natural gas is the effect they may have in controlling structures in overlying sediments in the Coastal Plain Province.

Mesozoic Rocks

Rocks of Mesozoic age in Delaware are chiefly Cretaceous, although Triassic sediment may form a wedge in the southern part of the state. Layers of conglomerate, sandstone, and shale of Triassic age are reported from some deep wells in Maryland a few miles south of the Delaware state line. Such a mixture of porous and non-porous beds may make excellent conditions for the storage of natural gas; however, at the present time, one can only speculate as to the continuity of these beds and the possibility of their having sufficient closure.

Unconformably overlying the Triassic sediments and the crystalline basement complex are the sediments of Cretaceous age. The lower part of the Cretaceous section is composed of non-marine sands and clays. It is believed that some of these sands are channel deposits. This fact combined with the southeasterly dip of the formations may provide excellent conditions for the storage of natural gas, but again the subsurface stratigraphy is not understood in enough detail to make any specific recommendations.

The Magothy Formation overlies the non-marine Cretaceous section. It is composed of lignitic shales, mixed with cross-bedded quartzose sands. These sands are also channel or near-shore marine deposits and conceivably could provide reservoirs for the storage of natural gas. The Magothy Formation is over 100 feet thick at Dover, Delaware.

The Magothy is overlain by typical marine formations of the Matawan and Monmouth Groups. The Matawan Group grades from silts and clays near the base to fine sands at the top. The sandy members of this group have sufficient porosity and permeability, in the area in which they outcrop, to act as storage reservoirs. However, down dip they tend to become more clayey and impervious. The Monmouth Group which overlies the Matawan is composed of fine to medium sands which also have sufficient porosity and permeability for storage. Once again, however, the problem is that of finding a structure with suitable closure.

Cenozoic Rocks

The Cenozoic rocks of Delaware are chiefly of Paleocene, Eocene, Miocene, and Pleistocene age. The Paleocene and Eocene parts of the section are similar to the Upper Cretaceous marine deposits previously described. They consist of marine shelf deposits of silt and sand with sufficient porosity to store natural gas but no proven structures which would serve as traps. The greensands of this series act as aquifers in the central part of the state. Structures may be developed locally in the upper margins of these sands due to the unconformable relationship of the overlying beds. If suitable structures are present, the lower Tertiary greensands could probably be used for the storage of natural gas.

The Miocene series is composed of alternating layers of sand and clay which wedge out towards the northwest. The top of the series dips approximately nine feet per mile, while the bottom of the series dips approximately 18 feet per mile. Within the series there are alternating layers of sand and clay which presumably could supply storage reservoirs. In addition, there may be sand lenses in the Miocene sediments which might provide small storage areas.

The Miocene is unconformably overlain by Pleistocene gravels, sands, and clays. The unconformable relationship which the Pleistocene has to the underlying strata no doubt provides suitable structures as far as closure is concerned, but the Pleistocene sediments make up only a thin mantle which covers the state and are not of sufficient thickness or strength to provide the necessary pressure required to contain large quantities of natural gas.

Summary

There are no areas which have been proven suitable for the storage of natural gas in Delaware. However, there are several areas which may deserve investigation. These possible storage beds are here listed. Figure 3 shows these potential areas diagrammatically. (1) The erosional surface on the top of the pre-Cretaceous crystallines may have been responsible for forming structural or stratigraphic traps in the Cretaceous sediments which unconformably overlie the crystalline. (2) The Triassic wedge in the southern part of the state may form a stratigraphic trap. (3) In the non-marine Cretaceous formations, high porosity channel deposits and sandy lenses may provide storage beds. (4) High porosity channel deposits in the Magothy Formation may be surrounded by impervious clays and form a trap. (5) Limited greensand layers in the marine Cretaceous and Lower Tertiary may also be suitable for gas storage. (6) Stringer sand bodies and sandy wedges which are unconformably overlain by impervious clays in the Miocene section may provide excellent traps.

The Use of Natural Gas in Delaware

All of the gas sold in Delaware at the present time is natural gas with the exception of propane-air which is sold and distributed by the Georgetown Service and Gas Company and liquified petroleum gases sold in bottles and tanks in other communities having no distribution system. All of the natural gas is piped in by the Transcontinental Gas Pipe Line Corporation of Houston, Texas. This gas is chiefly methane of 0.59 specific gravity and heat content of approximately 1040 B.T.U. per cubic foot.

The two major distributors in the state are the Delaware Power and Light Company and the Eastern Shore Natural Gas Company. Delaware Power and Light supplies gas to the northern part of New Castle County, and Eastern Shore Natural Gas Company services the remainder of the state. Table 2 shows the actual or estimated sale of natural gas in Delaware for 1959, 1960 and 1961.

Table 2 - Sales of Natural Gas in Delaware for Three Years

Year	Estimated Or Actual	Annual Sales In Mcf
1959	Actual	9,698,968
1960	Estimated	11,368,400
1961	Estimated	13,816,600

With the expected rise in population and increasing industrial demands, the sales of natural gas in Delaware will probably continue to increase. The only storage facilities in the state are those owned by the city gas distribution companies. Several of these companies have 30,000 gallon propane storage tanks and propane air plants. These plants are generally used for peak shaving and emergency standby supplies.

Regulations Affecting Natural Gas Storage

There are very few Delaware state legal regulations which would affect the storage of natural gas in Delaware. Storage would be, of course, subject to federal regulations which are more precise and detailed than any Delaware statutes. State legislation would depend on the circumstances of any particular case involving the storage of natural gas but might very well be subject to public utility regulations. By statute, a public utility includes everyone who operates any "manufactured gas, (or) natural gas... service, system,

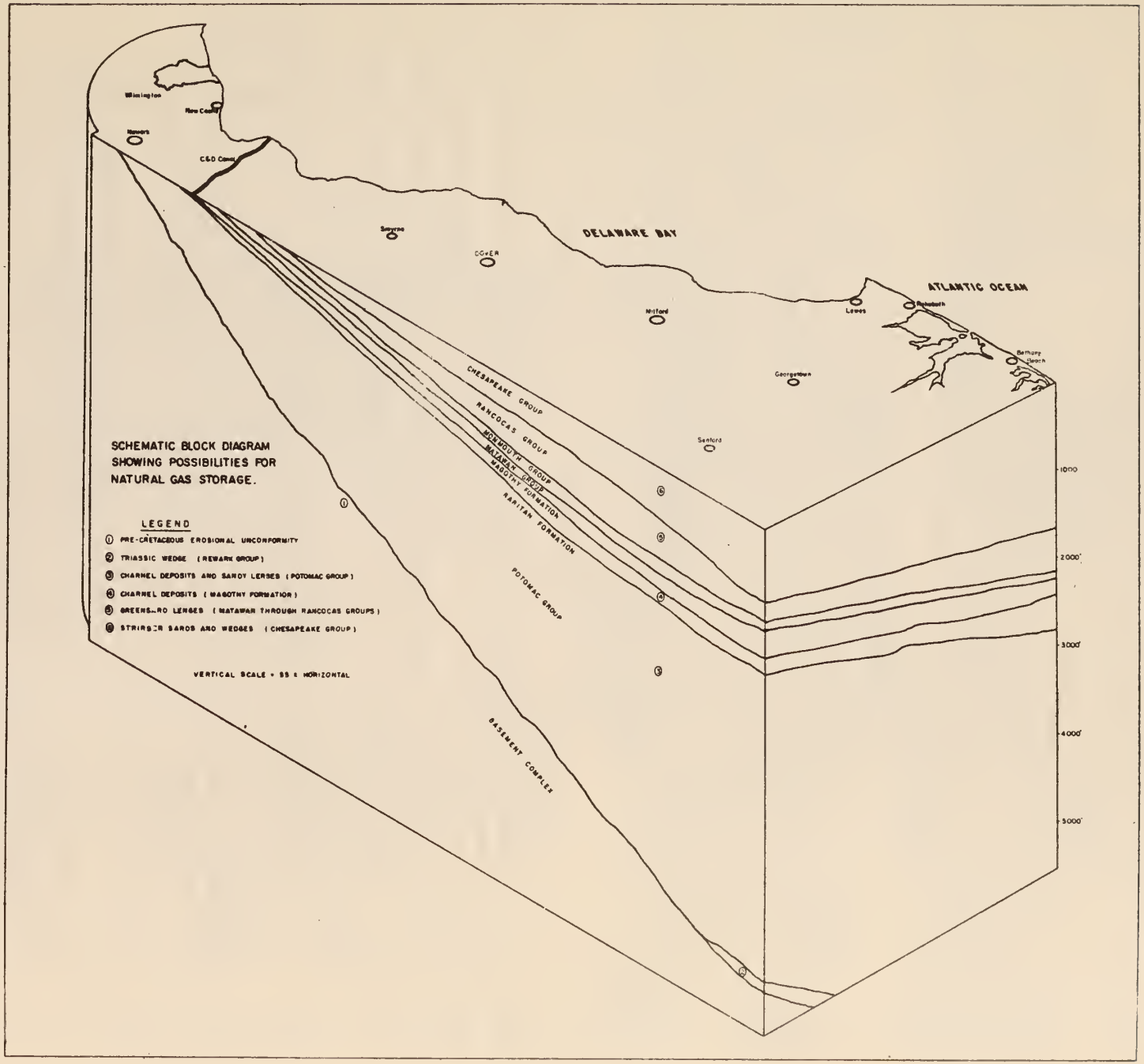
SCHEMATIC BLOCK DIAGRAM
SHOWING POSSIBILITIES FOR
NATURAL GAS STORAGE.
LEGEND
① PRE-CRETACEOUS EROSIONAL UNCONFORMITY
② TRIASSIC WEDGE (NEWARK GROUP)
③ CHANNEL DEPOSITS AND SANDY LENSES (POTOMAC GROUP)
④ CHANNEL DEPOSITS (MAGOTHY FORMATION)
⑤ GREENSAND LENSES (MATAWAN THROUGH RANCOCAS GROUPS)
⑥ STRIPPER SANDS AND WEDGES (CHESAPEAKE GROUP)
VERTICAL SCALE = 55 x HORIZONTAL
DELAWARE BAY
ATLANTIC OCEAN
Wilmington
New Castle
Newark
C&D Canal
Smyrna
DOVER
Milford
Lewes
Rehoboth
Bethany Beach
Georgetown
Seaford
CHESAPEAKE GROUP
RANCOCAS GROUP
MONMOUTH GROUP
MATAWAN GROUP
MAGOTHY FORMATION
RARITAN FORMATION
POTOMAC GROUP
BASEMENT COMPLEX
1000
2000'
3000'
4000'
5000'

Figure 3

plant or equipment, for public use." (26 Del. Code, #101). The Public Service Commission has general regulatory supervision over all public utilities and their property (26 Del. Code, #121). The Public Service Commission also controls public utilities entering upon a public utility activity (#162).

Another chapter of the law relating to gas companies gives corporations organized for "production, distribution, and sale of gas" certain powers with respect to the installation of equipment, laying out pipelines, etc. This law, as well as the general common law, implies that gas companies have a duty to conduct their activities so as not to endanger life or interfere with the use of other property. Any contamination or pollution of property such as soil, surface water, and ground water due to the storage of natural gas would be prohibited by common law (personal communication with the Office of the Attorney General). In Delaware, as in most of the eastern states, the natural resources beneath the land are the property of the landowner.

Recommendations and Summary

The possibility of the storage of natural gas in Delaware is questionable. At the present time, no suitable structures are definitely known; however, potential areas may be inferred from the limited information of the general stratigraphy of the state. The writers do not believe that any area in the extreme northern part of the state would lend itself to the storage of natural gas because of the dense, crystalline nature of the rocks in that area. However, possibilities do exist in the Coastal Plain.

The expected increase in the demand for natural gas, both by domestic and industrial consumers, makes Delaware an excellent location to consider for the development of natural gas storage sites. It is not expected that state legislation would be a serious problem when considering the storage of natural gas in Delaware, although the storage company would probably come under the control of the Public Service Commission.

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Table 3

NOMENCLATURAL CHART OF FLORIDA

ERA	SYSTEM	SERIES	PANHANDLE	PENINSULA
CENOZOIC (SURFACE)	QUATERNARY	RECENT	UNNAMED SAND, PEAT AND CLAY	
		PLEISTOCENE	LAKE FLIRT MARL SILVER BLUFF FORMATION PAMLICO FORMATION WICOMICO FORMATION OKEFENOKEE FORMATION COHARIE FORMATION	CONTEMPORANEOUS CARBONATE AND SAND DEPOSITS CALOOSAHATCHEE FORMATION
	?PLIO-PLEISTOCENE		HIGH LEVEL ALLUVIAL AND DELTAIC DEPOSITS	
	TERTIARY	MIOCENE	CHOCTAWHATCHEE STAGE ARCA FACIES CANCELLARIA FACIES YOLDIA FACIES ALUM BLUFF STAGE SHOAL RIVER FACIES OAK GROVE FACIES TAMPA STAGE CHATTAHOOCHEE FACIES ST. MARKS FACIES	TAMIAMI FACIES SOUTH ARCA FACIES DOWNDIP BOPHORA FACIES CHIPOLA FACIES HAWTHORN FACIES ALACHUA FACIES BONE VALLEY FORMATION MIOGYPSINA FACIES
		OLIGOCENE	VICKSBURG SUWANNEE LIMESTONE LATE VICKSBURG BYRAM FORMATION EARLY VICKSBURG MARIANNA LIMESTONE	SUWANNEE LIMESTONE BYRAM FORMATION
		EOCENE	JACKSON AGE: OCALA GROUP	CRYSTAL RIVER FORMATION WILLISTON FORMATION INGLIS FORMATION
			CLAIBORNE AGE: LISBON	AVON PARK LIMESTONE
			CLAIBORNE AGE: TALAHATTA	LAKE CITY LIMESTONE
			WILCOX AGE: UNDIFFERENTIATED WILCOX	OLDSMAR LIMESTONE
		PALEOCENE	MIDWAY AGE: UNDIFFERENTIATED MIDWAY	CEDAR KEYS LIMESTONE
MESOZOIC (SUBSURFACE)	CRETACEOUS	GULF	NAVARRO AGE: BEDS OF NAVARRO AGE (?) (ABSENT IN PART)	LAWSON LIMESTONE
			TAYLOR AGE (SELMA): BEDS OF TAYLOR AGE	BEDS OF TAYLOR AGE
			AUSTIN AGE (SELMA): BEDS OF AUSTIN AGE	BEDS OF AUSTIN AGE
			EAGLEFORD AGE (EUTAW): EUTAW	BEDS OF EAGLEFORD AGE
			WOODBINE AGE (TUSCALOOSA): UPPER, MILLER SAND; MARINE; LOWER, MOYE (PILOT) SAND (ATKINSON FORMATION)	BEDS OF WOODBINE AGE
		COMANCHE	UNDIFF.: UNDIFFERENTIATED LOWER CRETACEOUS	COMANCHE ?JURASSIC LIMESTONE IN SOUTH PENINSULA
	TRIASSIC ?		UNNAMED RED BEDS AND BASALT (INTRUSIVE)	QUARTZ DIABASE, POSSIBLE SILL
PALEOZOIC	SILURIAN / DEVONIAN		UNNAMED SHALES AND SANDS	
	SILURIAN / ORDOVICIAN		EARLY SILURIAN OR LATE ORDOVICIAN AND ORDOVICIAN OR SILURIAN BLACK SHALE	
	CAMBRIAN / ORDOVICIAN		QUARTZITIC SANDSTONE	
	CAMBRIAN / PRE-CAMBRIAN		?	PYROCLASTIC ROCKS OF PALEOZOIC OR PRE-CAMBRIAN AGE
CRYPTOZOIC	PRE-CAMBRIAN		CRYSTALLINE ROCKS	

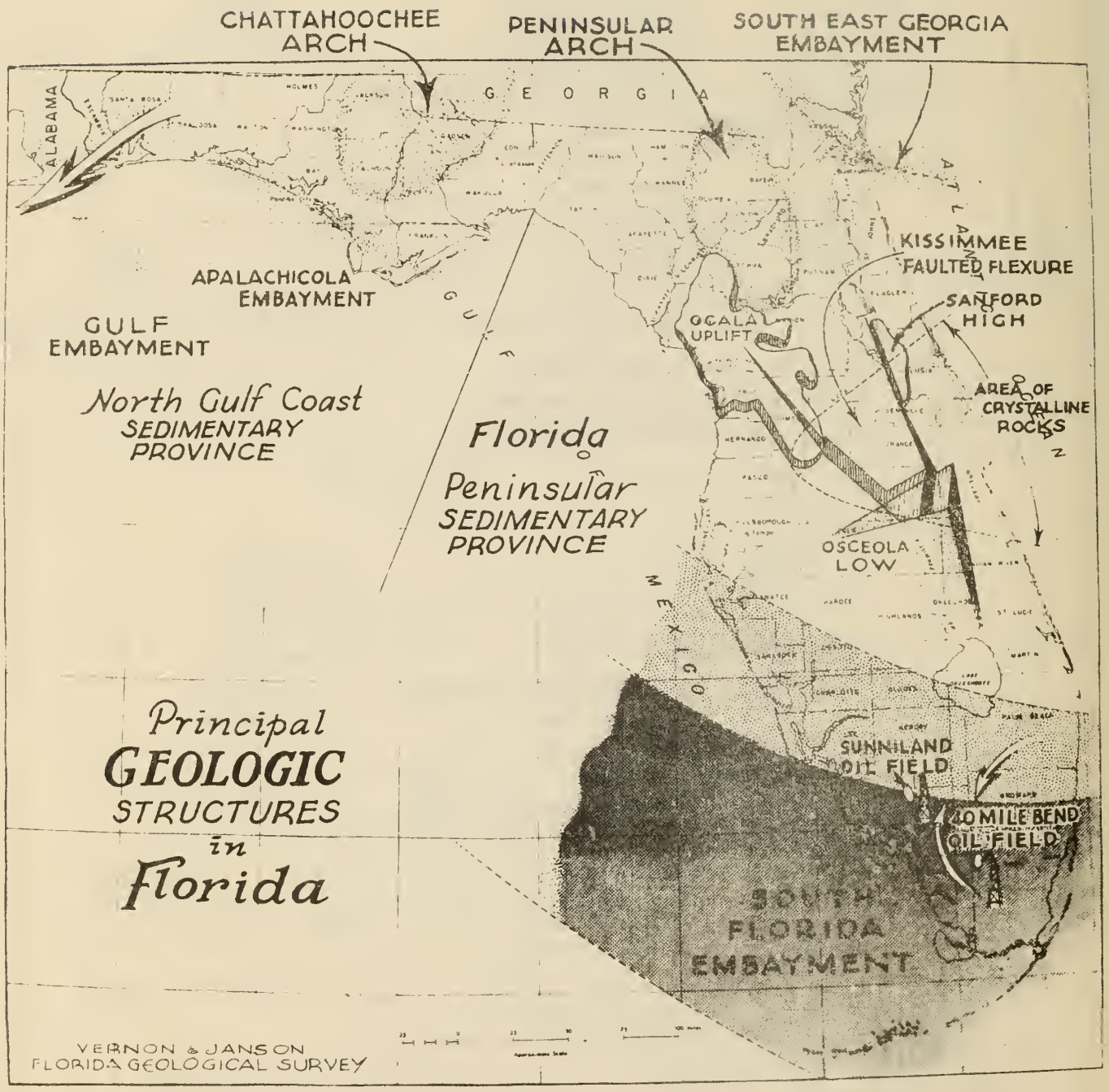

CHATTAHOOCHEE ARCH
PENINSULAR ARCH
SOUTH EAST GEORGIA EMBAYMENT
ALABAMA
GEORGIA
ATLANTIC
KISSIMMEE FAULTED FLEXURE
SANFORD HIGH
APALACHICOLA EMBAYMENT
GULF EMBAYMENT
OCALA UPLIFT
AREA OF CRYSTALLINE ROCKS
North Gulf Coast SEDIMENTARY PROVINCE
Florida Peninsular SEDIMENTARY PROVINCE
OSCEOLA LOW
GULF OF MEXICO
Principal GEOLOGIC STRUCTURES in Florida
SUNNILAND OIL FIELD
40 MILE BEND OIL FIELD
SOUTH FLORIDA EMBAYMENT
VERNON & JANSON
FLORIDA GEOLOGICAL SURVEY

Figure 4

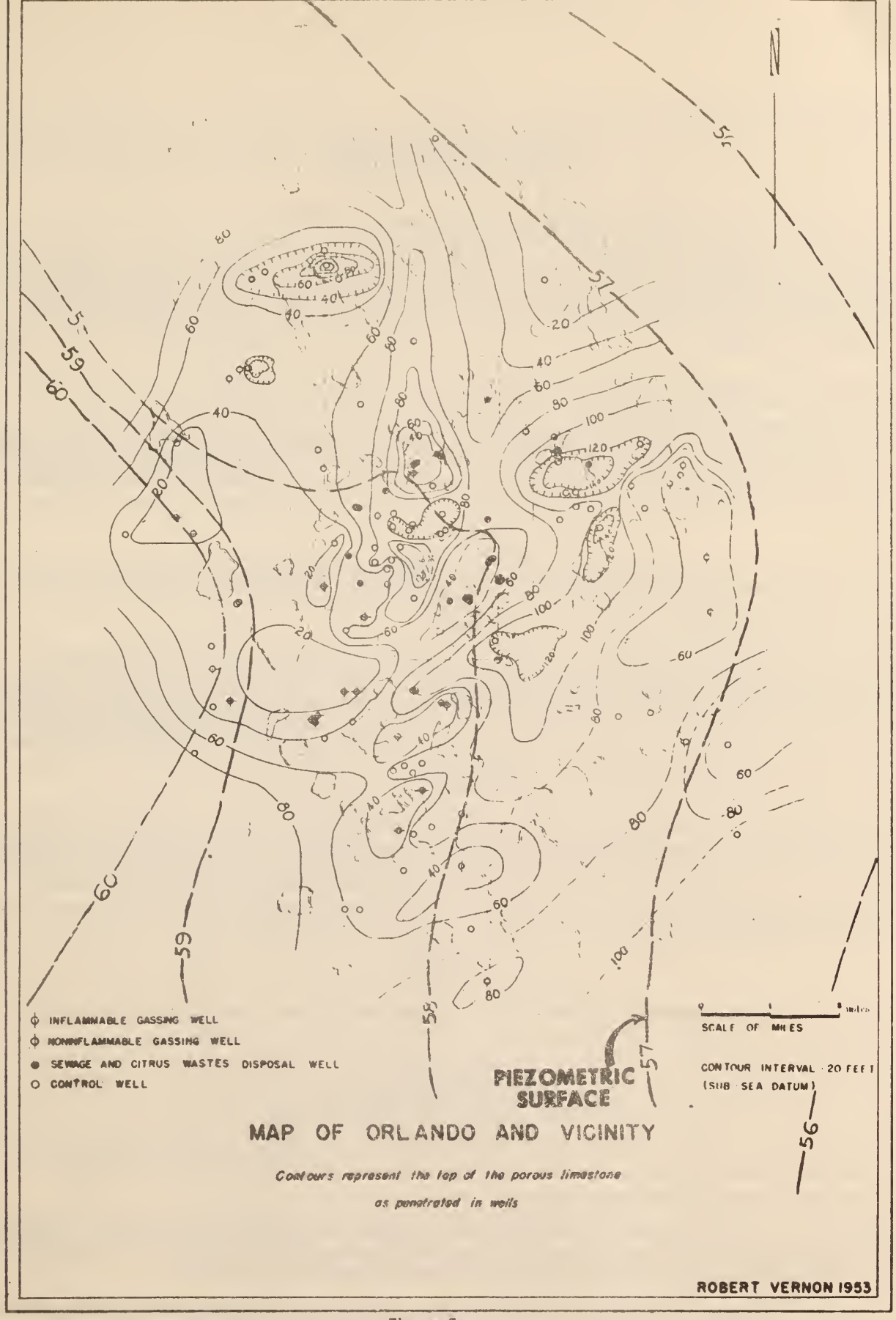

INFLAMMABLE GASSING WELL
NONINFLAMMABLE GASSING WELL
SEWAGE AND CITRUS WASTES DISPOSAL WELL
CONTROL WELL
PIEZOMETRIC SURFACE
SCALE OF MILES
CONTOUR INTERVAL 20 FEET (SUB SEA DATUM)
MAP OF ORLANDO AND VICINITY
Contours represent the top of the porous limestone as penetrated in wells
ROBERT VERNON 1953

Figure 5.

FLORIDA

Robert O. Vernon, Director
Florida Geological Survey

Possibilities of Underground Storage.

The subsurface sediments of Florida are primarily carbonates and evaporates with considerable porosity and permeability near the ground surface. These sediments are filled with copious supplies of water held under artesian pressure by more impervious clastic sediments. Table 3 summarizes the formations and rock types present in Florida. Figure 4 is a pictorial summary of the principal geologic structures.

States now storing gas in the subsurface have utilized depleted oil or gas fields, other porosity or structural traps, and cavities dissolved in salt beds or mined in impervious rock.

There are no depleted oil or gas fields in Florida, and, of the two productive fields, the Forty Mile Bend Field, Dade County, was marginal, and further development and exploration has been abandoned temporarily. The Sunniland Field, Collier County, produces at a very low decline rate and is expected to produce for another 60 years. All wells are developed below 10,500 feet of depth in Lower Cretaceous carbonates.

There are no salt beds, igneous rock, or dense sediments of sufficient areal extent, or that are located near the ground surface, to allow their use for gas storage. Probably the only possibility of the storage of gas in the subsurface of Florida would be in shallow, porous sediments eroded to considerable relief and covered by impervious clastics and carbonates.

The Miocene sediments of peninsular Florida were deposited upon an eroded surface of porous and permeable carbonates of the Eocene and Oligocene stages. A topography having considerable relief was developed upon this surface, and it was covered by sediments of low permeability to form local porosity traps in the tops of buried hills. In the Orlando area, this buried surface has been mapped (figure 5). The introduction of citrus and other wastes into the subsurface has resulted in the formation of methane gases which have accumulated in the porosity traps. In the southern part of Orange County, some production has been encountered, sufficient to furnish the needs of several homes.

The subsurface of the central part of Florida and the Orlando area is filled by fresh water under artesian pressure and is an important source of the state's water supply. For this reason, the storage of gas in this area would probably not be wise, but there is the possibility that successful storage could be made along coastal areas and in areas lying generally south of Lake Okeechobee in similar traps where the water is too highly mineralized for use. The details necessary to outline structures and porosity traps have not been developed.

Compendium

There are limited possibilities in Florida for the subsurface storage of gas, these largely unproved.

GEORGIA

Garland Peyton, Director
Department of Mines, Mining and Geology

Previous reports submitted from Georgia on possibilities for underground storage of liquid petroleum hydrocarbons have not been too optimistic in relation to geologic formations considered most desirable as well as suitable for this utilization.

In the main, previous reports have suggested the possibility of storage in cavities in hard crystalline rocks, of injection into porous rock limited to favorable structure (Paleozoic rocks), and possible storage in sedimentary rocks such as are found in the lower Coastal Plain of Georgia.

Dr. S. M. Herrick, Paleontologist of the U. S. Geological Survey, recommends the investigation of possibilities of using the Blufftown Formation in the vicinity of Cusseta in Chattahoochee County, Georgia.

Doctor Herrick points out that in this locality a horizon of about 500 feet thickness exists which is mostly clay and is above most of the water-bearing rocks. He feels that this might be found to offer suitable possibilities in connection with the storage of liquid petroleum products.

A recent article in the November 28, 1960, issue of Oil and Gas Journal carried pictures of underground man-made caverns in crystalline rocks excavated for storage of liquid petroleum products. The article points out that a mined-granite cavern with capacity of 1,000,000 barrels will be built between Atlanta and Jonesboro, Georgia, in conjunction with the new Transcontinental Gas Pipe Line now being installed across Georgia. The locality which has been selected as a result of core drilling to a depth of some 500 feet in some eight or ten drill holes is in Clayton County between the towns of Morrow and Jonesboro. This pipe line will stretch from near Houston, Texas, to Danville, Virginia. (See Oil and Gas Journal of Oct. 3, 1960, page 66). The pipe line will be operated by Transco's subsidiary, Trans-Southern Pipeline Corporation.

Some time ago, representatives of another pipe line corporation made a trip to Georgia and conducted geologic examinations in the vicinity of Elberton, with a view to possibly preparing an underground storage space in that area similar to the one described above. No definite plan on this latter development, however, has been announced as yet.

ILLINOIS

Alfred H. Bell
Head, Oil and Gas Section, Geological Survey

Abstract

Natural gas from the Mid-Continent and Gulf Coast regions is being stored underground in Illinois in six areas as of January 1, 1961, and similar storage projects are planned in at least five other areas. The storage reservoirs are of two main types: (1) "aquifers," those that originally contained only water, and (2) those that contained oil or gas, as well as water. Gas storage reservoirs now in use have an estimated total capacity of 184 billion cubic feet.

Introduction

Natural gas from the Mid-Continent and Gulf Coast regions is being stored underground in Illinois in six areas as of January 1, 1961, and similar storage projects are planned in at least five other areas. The storage reservoirs are of two main types: (1) "aquifers," those that originally contained only water, and (2) those that contained oil or gas, as well as water.

Underground storage facilities perform a vital function in making gas available to consumers in the necessary quantities at times of high demand and at a cost lower than that of direct pipeline delivery from the distant sources. It is thus possible to serve many more consumers than could be served without the use of underground storage.

Natural gas has been stored underground in Illinois since 1953, and the use of underground storage has been steadily increasing. In 1951, the Illinois Commerce Commission consulted the Illinois State Geological Survey about the feasibility of underground storage. Since then, the Survey has kept in touch with developments and has continued to study the geology of the storage sites. The Survey has assisted by discussions with the staffs of the Illinois Commerce Commission and the companies concerned and by attendance at hearings before the Commission. Much information on the geology and engineering of the storage projects is contained in the testimony by geologists and engineers in transcripts of the hearings on file with the Commission.

Beginning in June, 1959, the Research Committee of the Interstate Oil Compact Commission undertook a study of the underground storage of natural gas in the United States. At subsequent meetings of the Research Committee in December, 1959, June, 1960, and December, 1960, Illinois and about 25 other states presented progress reports. The Illinois report included developments in underground gas storage up to December 1, 1960. The present report includes available information up to January 1, 1961.

The six areas in which gas is being stored underground in Illinois are Herscher in Kankakee County (no. 1 on index map, figure 6); Cooks Mills in Coles County (4); Troy Grove in LaSalle County (2);

Waterloo in Monroe County (9); Gillespie in Macoupin County (7); and Freeburg in St. Clair County (10). Similar gas storage operations are planned in at least five other areas: Mahomet in Champaign County (map no. 3); Crescent City in Iroquois County (5); Waverly in Morgan County (6); St. Jacob in Madison County (8); and North Tilden in Washington and St. Clair Counties (11).

The Herscher and Cooks Mills storages by the Natural Gas Storage Company of Illinois and the future Mahomet storage by the Peoples Gas Light and Coke Company supply the City of Chicago. The Troy Grove and future Crescent City operations by the Northern Illinois Gas Company supply many municipalities in northern Illinois outside of Chicago.

The Northern Illinois Gas Company and others share in the use of the Herscher storage with the Natural Gas Storage Company of Illinois, a subsidiary of the Peoples Gas Light and Coke Company of Chicago. The Gillespie and Freeburg storages and the future North Tilden storage by the Illinois Power Company supply gas to local communities in southwestern Illinois. The Waterloo and future St. Jacob storages by the Mississippi River Fuel Corporation supply St. Louis, Missouri, and surrounding communities.

The following individuals have been especially helpful in furnishing the basic data and in suggesting revisions and corrections to the preliminary report dated December 1, 1960: O. C. Davis, W. L. Clark, and K. R. Larson of the Natural Gas Storage Company of Illinois; Joseph Gauthier, Harold R. Schwalm, and C. G. Nelson of the Northern Illinois Gas Company; Kenneth Robertson of the Illinois Power Company; R. B. Harkins of the Panhandle Eastern Pipeline Company; and Carl Temple of the Mississippi River Fuel Corporation. I also am indebted to Carl W. Sherman, Head of the Petroleum Engineering Section of the Illinois State Geological Survey, who assisted in preparing this report.

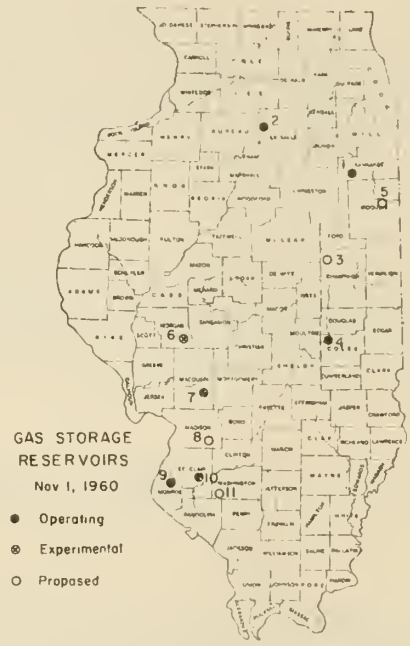


Figure 6. Location of underground gas storage reservoirs in Illinois.

1 Herscher
2 Troy Grove
3 Mahomet
4 Cooks Mills
5 Crescent City
6 Waverly
7 Gillespie
8 St. Jacob
9 Waterloo
10 Freeburg
11 North Tilden

The underground reservoirs that originally contained fresh water or salt water, commonly referred to as aquifers, include the reservoirs of largest capacity in Illinois -- for example, Herscher. Those that originally contained gas or oil or both, along with some water, include several gas reservoirs where the wells were capable of producing gas but where the gas has not been marketed -- for example, Cooks Mills and Freeburg. In these storage reservoirs, the injected gas mixes with the gas originally in the reservoir, and during the initial stage the gas withdrawn is a mixture of both.

Estimated capacities of operating gas storages in Illinois, as of January 1, 1961, are shown in table 4. Volumes are given in thousands of cubic feet (Mcf).

Table 4 - Estimated Capacities of Operating Gas Storages in Illinois
December 1, 1960

	Working gas Capacity - Mcf	Cushion Gas - Mcf	Total Mcf
Herscher Galesville	45,000,000	45,000,000	90,000,000
Herscher Mt. Simon	39,000,000	28,000,000	67,000,000
(Herscher total 157 million Mcf)			
Troy Grove	11,000,000	7,000,000	18,000,000
Cooks Mills	1,004,000	984,000	1,988,000
Gillespie	31,000	115,000	146,000
Waterloo	413,000	100,000	513,000
Freeburg	1,810,000	4,590,000	6,400,000
	98,258,000	85,789,000	184,047,000

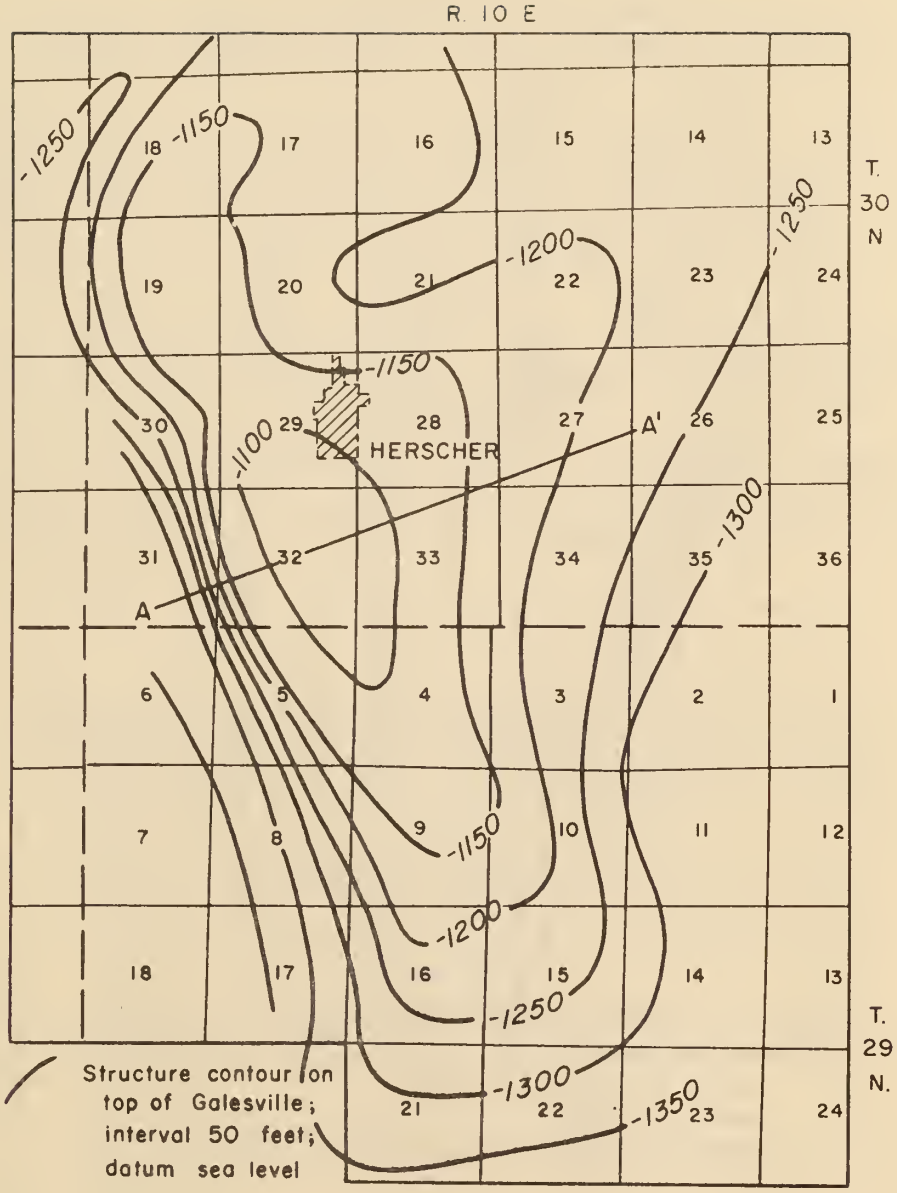


Figure 7. Structure of the Galesville Sandstone at the Herscher Gas Storage Dome (contours after map by the Natural Gas Storage Company of Illinois)

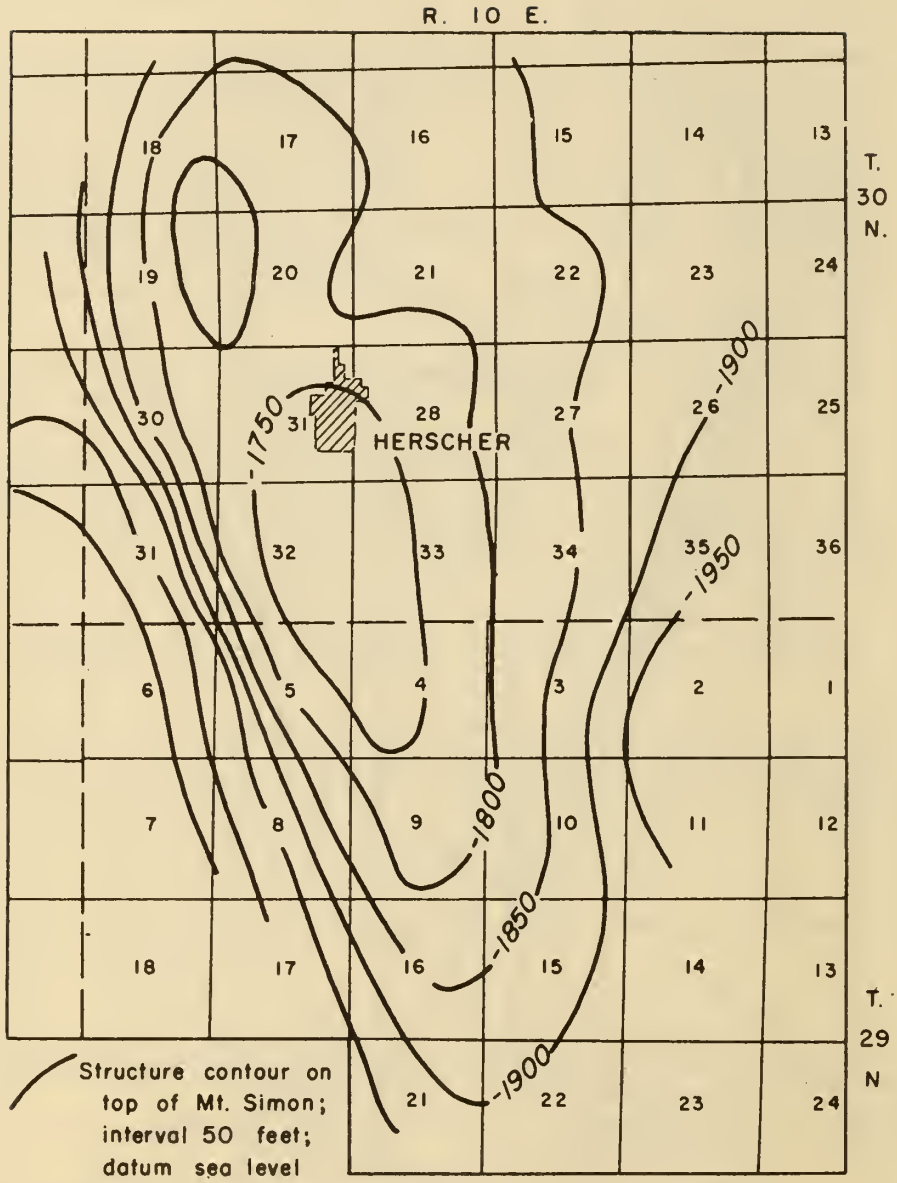


Figure 8. Structure of the Mt. Simon Sandstone at the Herscher Gas Storage Dome (contours after map by the Natural Gas Storage Company of Illinois)

Future Development

Because several companies are actively seeking geologic structures that are suitable for gas storage, it seems likely that additional storage projects will be undertaken during the coming year. Some of the companies engaged in this work and some of their areas of exploration are: Natural Gas Storage Company of Illinois in McLean and adjacent counties; Northern Illinois Gas Company in northeastern Illinois; Central Illinois Light Company in Peoria, Woodford, and Tazewell Counties; Illinois Power Company in Tuscola region, Douglas County; and Central Illinois Public Service Company in Ashmore South Pool, Cumberland and Clark Counties.

Herscher Gas Storage Field

Operator: Natural Gas Storage Company of Illinois.

Location: Kankakee County, 12 miles west-southwest of the city of Kankakee and half a mile south of Herscher Village.

Geologic Investigations: The presence of an anticline in the subsurface bedrock has been known since the early 1900's from the drilling of several small oil wells, described by L. F. Athy (1928, p. 110). A structure contour map by D. J. Fisher (in Athy, 1928, fig. 27, p. 75) showing elevation of the St. Peter Sandstone in part of northeastern Illinois reveals the Herscher Anticline. In 1951, the Natural Gas Storage Company of Illinois undertook to outline the structure in greater detail and to determine whether suitable porous strata and caprock were present. In 1952, 104 shallow test wells were drilled to the Galena Formation and four deep tests were drilled and cored through the Galesville Sandstone.

The size and shape of the structure is shown in figure 7, a contour map of the top of the Galesville Sandstone, which was to be the gas storage reservoir. The cores provided the information on porosity and permeability of the Galesville needed to determine its suitability as a gas storage reservoir and the adequacy of the caprock immediately overlying the reservoir.

Test drilling to determine the feasibility of deeper gas storage to supplement the storage in the Galesville reservoir was done in 1957. The information obtained indicated the likelihood of a good storage in the Mt. Simon Sandstone at an approximate depth of 2,400 feet. A structure map of the Mt. Simon Sandstone is shown in figure 8, and the relationship of the Galesville and Mt. Simon Sandstones is shown in the cross section, figure 9.

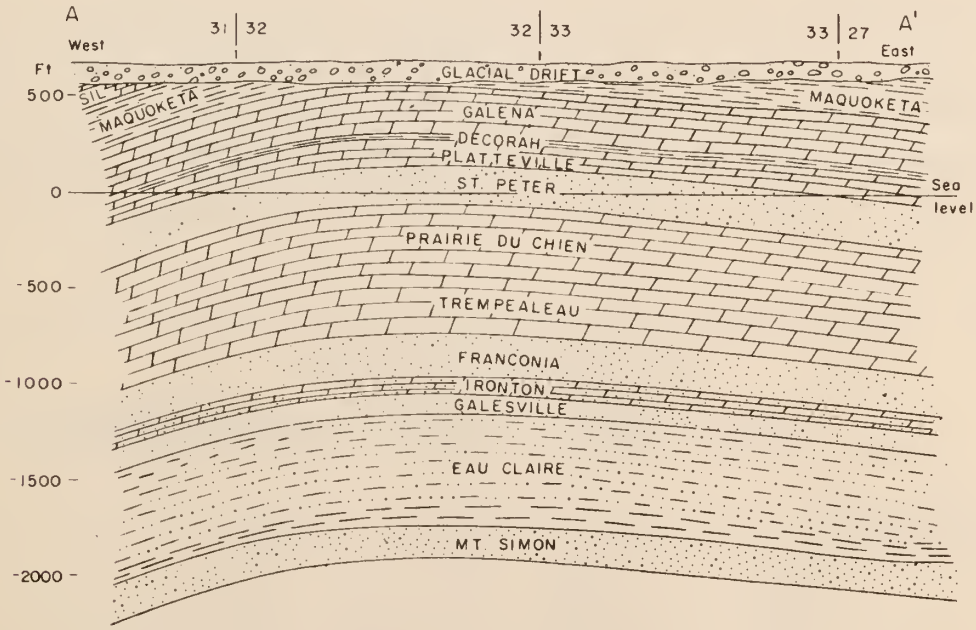


Figure 9. West-east cross section of Herscher Dome, vertical exaggeration x 3.3 (location shown on figure 7)

The following is quoted from "The Story of the Herscher Dome," by the Natural Gas Storage Company of Illinois (1957, p. 4-5).

"A total of 21 injection-withdrawal wells were completed in the Galesville Sandstone on the crest of the structure, using 660-foot spacing.

"Thirteen observation wells were drilled on the structure to the top of the reservoir at down dip positions on the flanks to observe water levels and follow the movement and effect of the gas bubble that was to be created.

"Gas injection was started on April 1, 1953, using two 150 hp. compressors with a total capacity of 15,000 Mcf per day. Initially, the five structurally highest wells were used for injecting gas into storage. Gas for storage operations was piped from a point on the Texas Illinois system later renamed Natural Gas Pipeline Company of America near Dwight, Illinois, through a single 30-inch line. A 10,000 hp. compressor station and a dehydration plant with 300 MMcf per day capacity were constructed to handle the gas on injection and withdrawal. The capacity of the dehydration plant has since been increased to 430 MMcf per day. The main plant was put into service on July 1, 1953. Injection rates were stepped up to approximately 200 MMcf per day with the large units when the main plant was put into operation."

During the last week in July, 1953, four months after gas injection was started, gas began to leak into one of the shallow water wells in the town of Herscher. Soon gas was leaking into all 33 village water wells. Gas injection was stopped one week after leakage had been detected. A search for the cause of the leakage was then undertaken by a variety of methods, but to date the cause has not been determined with certainty. However, it was found possible to control the leakage by the following four methods.

1. By limiting pressure during the injection cycle. At first, the injection pressure was limited to the natural formation pressure above the Galesville aquifer, but later the differential pressure was controlled between the Galesville gas bubble and the overlying Oneota Formation, the basal member of the Prairie du Chien Series.

2. By recycling the gas from vent wells in the Galena and St. Peter formations to the Galesville reservoir.

3. By pressurization of the Ironton Formation above the Galesville, but below the Oneota (see figure 9) by injection of water.

4. By relieving pressure in the Galesville reservoir through withdrawal of water from perimeter wells outside of the gas bubble. (This water is used for pressurization of the higher formations.)

The total amount of leakage from August 1, 1953, to October 2, 1955, when a recycling system began operation, was 2,947 million cubic feet at an average rate of 3.6 million cubic feet per day. Success of the control methods is indicated in the gradual downward trend in the amounts of gas recycled daily by years shown in table 5.

Table 5 - Daily Averages of Gas Recycled from the Galena and St. Peter Formations into the Herscher Galesville Reservoir in Millions of Cubic Feet

	Galena Formation			St. Peter Formation		
	Average	Maximum	Minimum	Average	Maximum	Minimum
1954						
1955 (Recycling system began Oct. 2, 1955; a loss to that date was 2.947 billion cu. ft.)				(Wells first drilled in early part of 1956)		
1956	12.4	15.4	9.8	3.6	4.4	2.7
1957	12.6	15.4	9.1	4.3	5.0	3.8
1958	13.2	15.2	10.6	3.8	4.5	3.1
1959	9.1	12.4	5.7	3.7	4.3	3.2
1960	10.3	20.2	9.9	3.2	2.9	0.9

NOTE: The above values are based on average daily recycled volumes for months.

The following table shows amounts of gas injected into and withdrawn from the Herscher Galesville reservoir, by years, and the maximum daily withdrawals by years at times of severe cold weather.

Table 6 - Herscher Galesville Reservoir
(in Mcf)

Year	Injected	Withdrawn	Inventory End of Year	Peak Day Withdrawal
1953	11,885,137	99,044	11,984,181	61,482
1954	6,178,390	340,111	17,822,460	157,777
1955	4,337,904	1,864,920	20,295,444	368,060
1956	6,490,803	1,539,393	25,246,854	414,996
1957	7,041,143	2,996,821	29,291,176	291,159
1958	9,124,414	8,528,832	29,886,758	411,467
1959	9,698,097	6,050,945	33,533,910	429,633
1960	7,826,486	7,165,722	34,194,674	473,391

Parallel information is shown in the next table for the Herscher Mt. Simon reservoir.

Table 7 - Herscher Mt. Simon Reservoir
(in Mcf)

Year	Injected	Withdrawn	Inventory End of Year	Peak Day Withdrawal
1957	21,667	---	21,667	None
1958	3,750,320	87,894	3,684,093	25,342
1959	6,034,283	364,495	9,353,881	52,098
1960	7,456,393	733,989	16,076,285	65,410

Although the capacity of the Galesville (figure 7) and Mt. Simon (figure 8) reservoirs in the Herscher Dome is less than originally anticipated, the total operation will undoubtedly be economically successful. The total investment in the Herscher storage project as of August 31, 1960, was $32,240,864, including the cost of cushion gas, but not of microwave installations and some minor items. The total cushion gas investment is $6,929,356, which includes $4,224,016 for the Galesville and $2,705,340 for the Mt. Simon. When these figures are compared with the 200 million dollars that would be required to build and equip another 30-inch pipeline from Texas (necessary to meet winter peak loads without storage), the advantage of the underground storage facilities is clearly evident.

The location of the principal pipelines which bring gas from the Mid-Continent and the Gulf Coast areas into Illinois is shown on the map (figure 10). This map also shows the location of the Herscher and Cooks Mills gas storages and the future Mahomet gas storage with the pipeline connections to them.

Troy Grove Gas Storage Field

Operator: Northern Illinois Gas Company.

Location: LaSalle County, midway between Mendota and LaSalle and near Troy Grove.

Geologic Investigations: The Northern Illinois Gas Company consulted the Illinois State Geological Survey in 1956 with regard to possible sites for underground gas storage in the northern part of Illinois. The available data suggested a search for a structural closure north of LaSalle along the axis of the LaSalle Anticline. Test core drilling that was begun in January, 1957, gave data which defined the Troy Grove Dome (figure 11), an asymmetrical, east-west trending anticline with 120 feet of closure on the Cambrian. The top of the Mt. Simon Sandstone and two basal sandstones of the Eau Claire Formation overlying it are used for gas storage. Dense shales and argillaceous dolomites form the caprock over these sandstones.

Tests of core samples indicated porosities in the storage sands ranging from 15 to 18 percent. Many samples of the caprock showed permeabilities below 10^{-6} millidarcies.

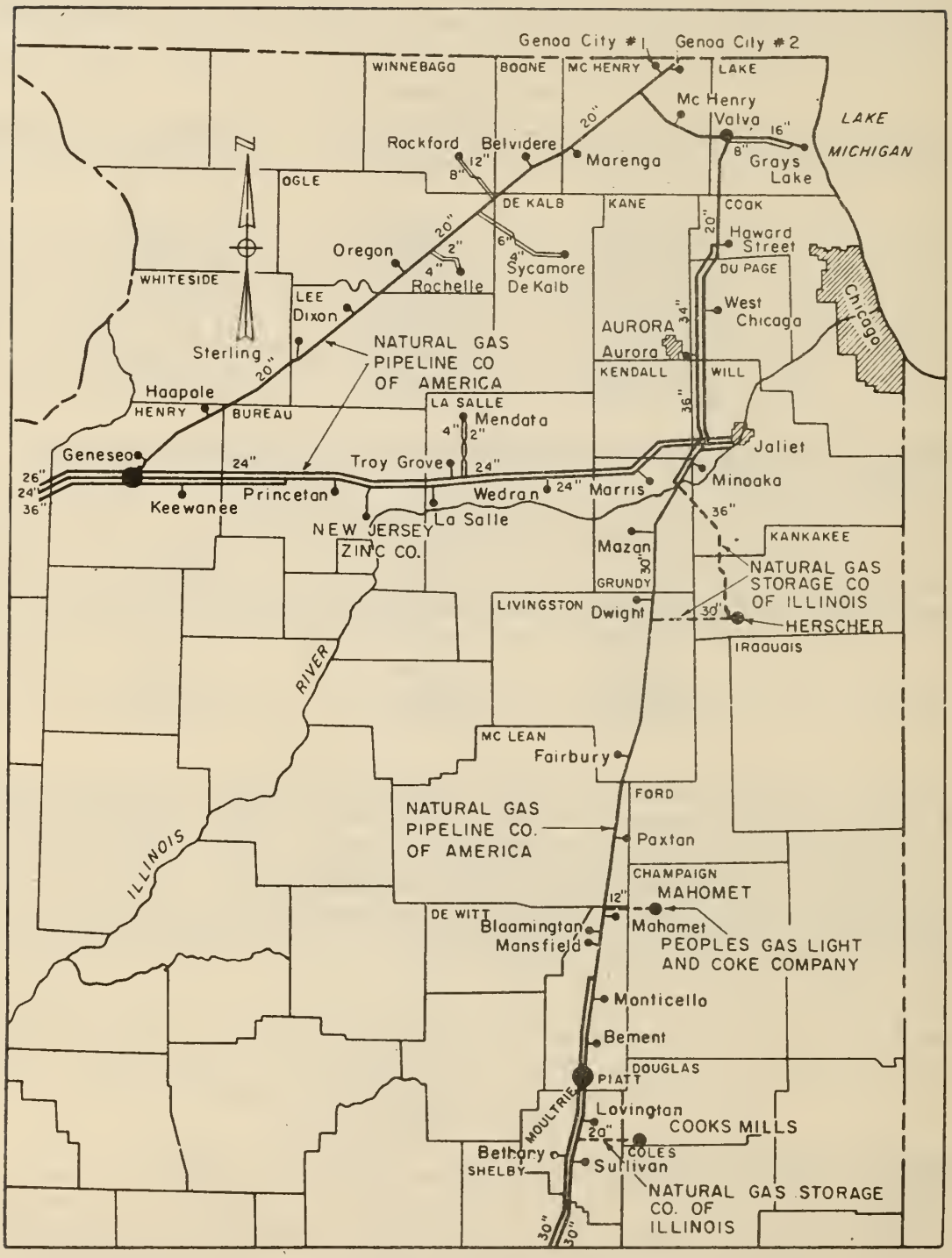


Figure 10. Portion of the State of Illinois showing location of pipelines of Natural Gas Pipeline Company of America, Natural Gas Storage Company of Illinois, and Peoples Gas Light and Coke Company (courtesy of Peoples Gas Light and Coke Company)

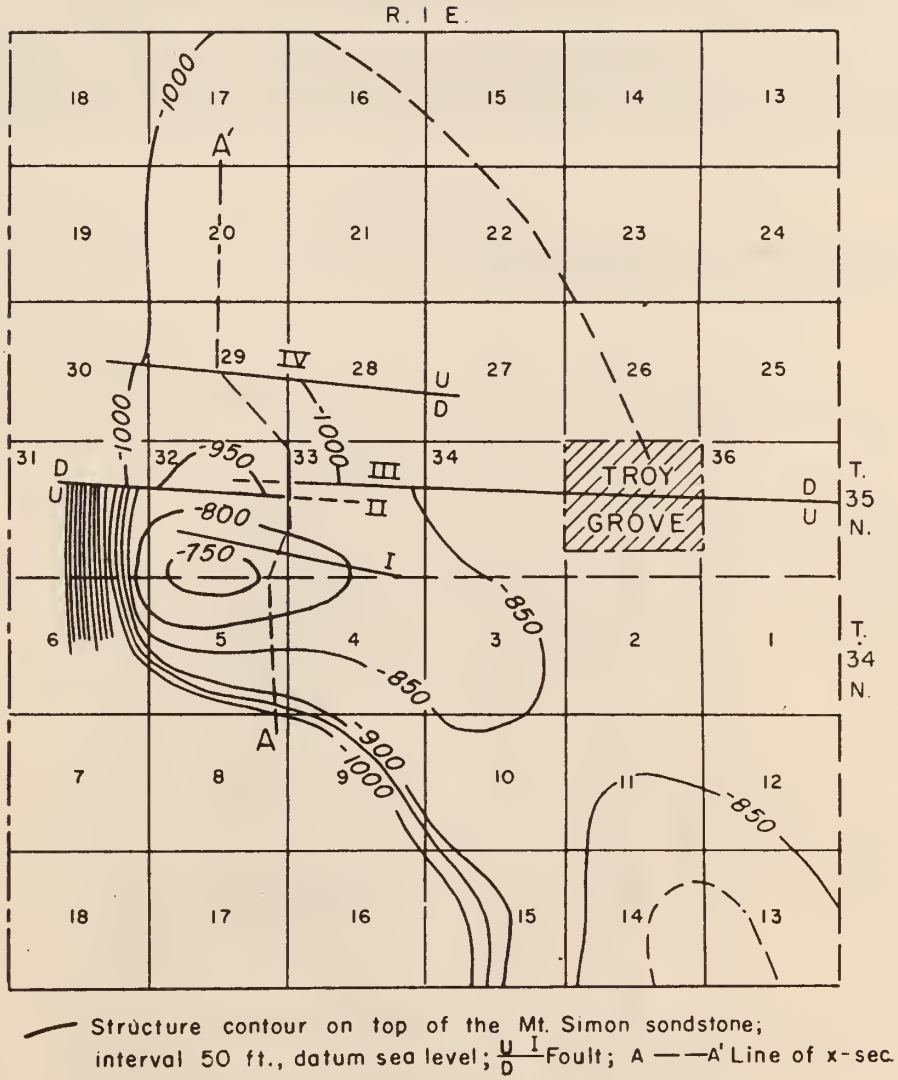


Figure 11. Structure of top of the Mt. Simon Sandstone at the Troy Grove Storage Project, LaSalle County, Illinois (by Northern Illinois Gas Company)

The test drilling indicated the presence of several faults, four of which are shown in figures 11 and 12. The displacement ranges from 15 to 160 feet.

In June, 1958, the Illinois Commerce Commission issued a certificate of convenience and necessity authorizing Northern Illinois Gas Company to test and develop the structure. Gas injection into the Mt. Simon Sandstone was started in July, 1958. Withdrawal of gas on a test basis began in December, 1959.

Gas is brought for injection into the Troy Grove storage reservoir by a 16-inch diameter lateral pipeline running north from the Natural Gas Pipe Line Company of America's trunk line near LaSalle.

The working gas capacity of the storage sands is estimated to be 11 billion cubic feet and the cushion gas capacity seven billion cubic feet, making a total capacity of 18 billion cubic feet.

Observations at the wells on both sides of the east-west faults indicated that where sandstone is in contact with sandstone, migration takes place freely across the faults, but there was no indication of upward migration of gas along the faults. Thus, it appears that the Troy Grove Dome will be an effective gas storage reservoir.

Mahomet Dome

Operator: Peoples Gas Light and Coke Company, Chicago.
Location: Western part of Champaign County.

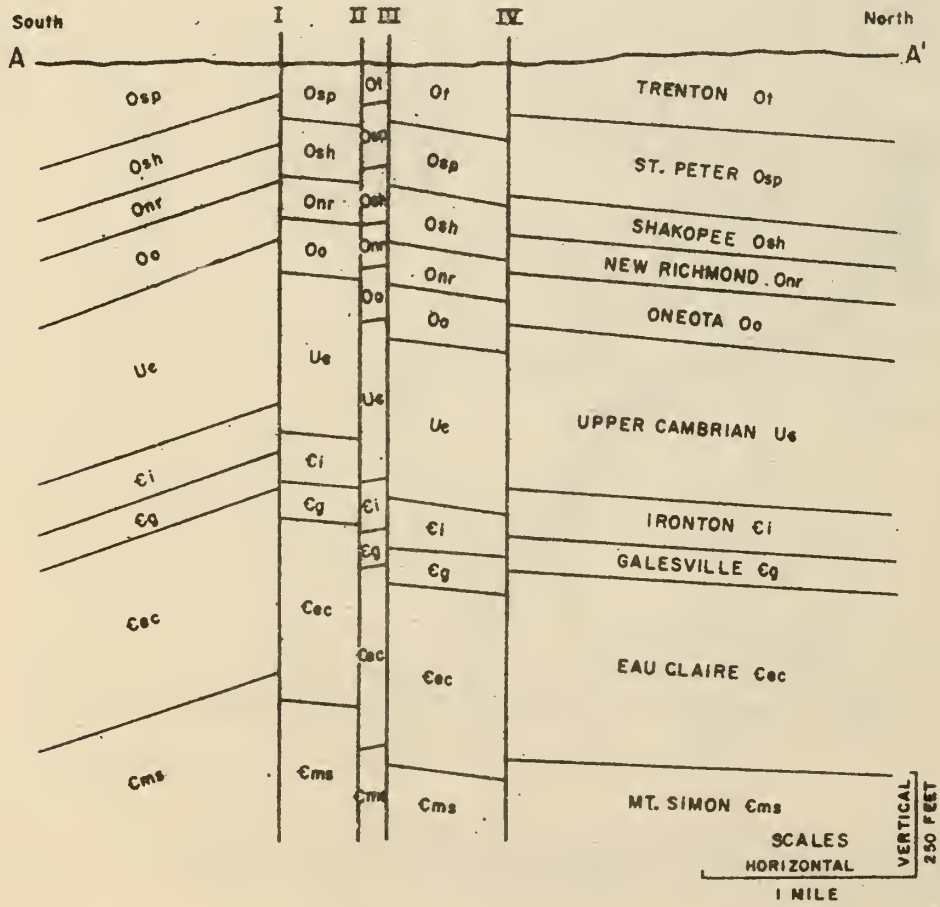


Figure 12. Cross section of Troy Grove aquifer (by Northern Illinois Gas Company)

Geologic Investigations: In their search for structures suitable for underground storage of gas, the Union Hill Gas Company, a subsidiary of the Peoples Gas Light and Coke Company of Chicago, investigated parts of the LaSalle Anticlinal Belt. In 1959 and 1960, they concentrated on an area between Mahomet and Gibson City.

The following is quoted from the testimony by a company geologist before the Illinois Commerce Commission.

"The presence of a large anticlinal structure in the northwestern corner of Champaign County, Illinois, has been confirmed by a detailed exploration program recently conducted by Union Hill Gas Storage Company. The principal structural feature is a domal anticlinal fold with a north-south major axis and approximately 150 feet of closure. No evidence of faulting has been encountered and the asymmetry of the structure, viewed in an east-west direction, is a characteristic exhibited by most large subsurface folds in northern Illinois along the LaSalle Anticlinal Belt.

"The St. Peter Formation, encountered at an average depth of 1,600 feet, is a porous and permeable sand, overlain by impermeable limestones, and suitable for the storage of natural gas.

"Underground storage of natural gas in the St. Peter Formation will in no way interfere with the local ground-water resources. No minable coals, minerals, nor commercial accumulations of either oil or natural gas have been encountered in any of the geological formations within the proposed storage area."

After several hearings, the Illinois Commerce Commission granted a certificate of convenience and necessity to Peoples Gas Light and Coke Company in August, 1960, to develop the structure for gas storage. Injection on a pilot scale is expected to begin in the spring of 1961.

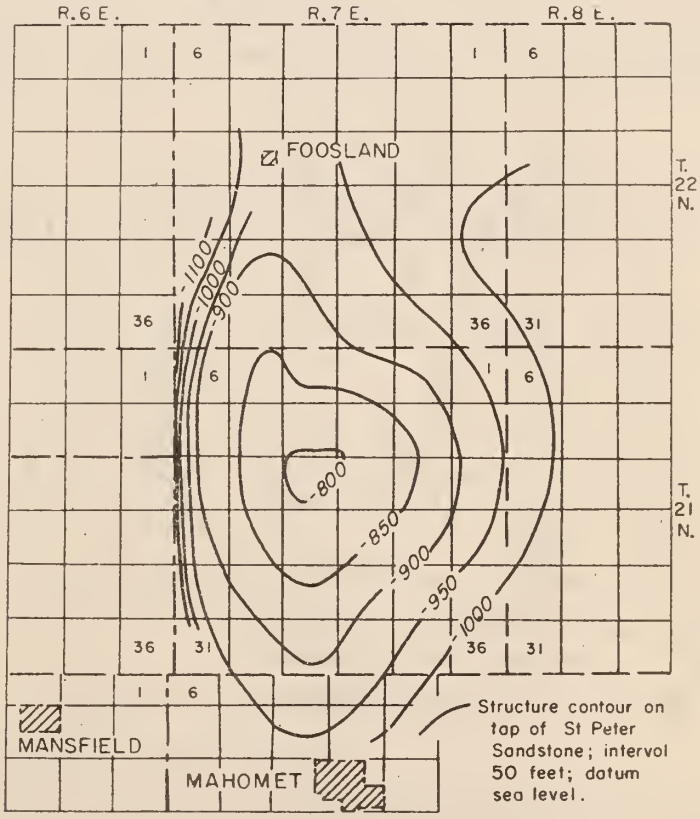


Figure 13. Structure of the St. Peter Sandstone at the Mahomet Dome, Champaign County, Illinois (after map by Peoples Gas Light and Coke Company, Chicago).

Cooks Mills Storage Area

Operator: Natural Gas Storage Company of Illinois.

Location: Part of Cooks Mills Consolidated Pool in Coles County, Illinois.

Geologic Investigations: The Cooks Mills Consolidated Oil Pool in Coles and Douglas Counties, Illinois, was discovered in 1941, but its major development did not take place until 1954. Oil and gas are produced from the Cypress, Aux Vases, and Spar Mountain sandstones and from the Ste. Genevieve Limestone, all of Mississippian age. In one part of the field, several wells produced gas from the Cypress, and the Natural Gas Storage Company of Illinois bought the storage rights and the gas in place. The domal structure in this area is shown in figure 14 and has been described by Whiting (1959).

Use of the Cypress Sandstone reservoir for storage in the Cooks Mills area began in 1958. At the end of that year, the reservoir contained 775,160 Mcf "top" storage gas and 993,736 Mcf cushion gas, or a total of 1,768,896 Mcf. At the end of 1959, the reservoir contained 1,003,880 Mcf top and 993,736 Mcf cushion gas, a total of 1,997,616 Mcf. At the end of 1960, the reservoir contained 2,120,373 Mcf. Peak daily withdrawal from the Cypress Reservoir in the Cooks Mills Field in 1960 was 29,284 Mcf.

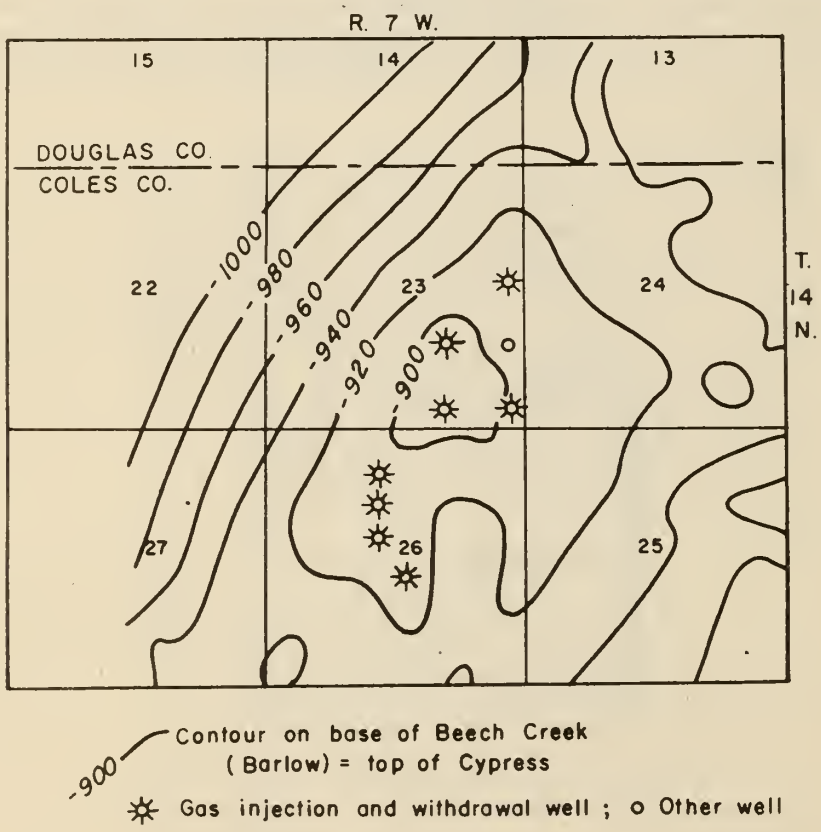


Figure 14. Part of Cooks Mills Consolidated Pool (after map by Natural Gas Storage Company of Illinois, June, 1960)

Table 8 gives monthly injections and withdrawals for the Cooks Mills Field for the year 1959.

Table 8 - Cooks Mills Gas Storage, 1959
(in Mcf, as metered at 14.65 psia)

	Injection	Withdrawal	Inventory
December, 1958			1,768,896
January, 1959	-	183,375	1,585,521
February	-	384,589	1,200,932
March	-	379,928	821,004
April	-	-	821,004
May	-	-	821,004
June	205,250	-	1,026,254
July	390,892	-	1,417,146
August	374,446	-	1,791,592
September	90,826	29,810	1,852,608
October	145,008	-	1,997,616
November	-	-	1,997,616
December	-	-	1,997,616

Gas for injection into the Cooks Mills Storage Reservoir is brought through a 20-inch lateral line, approximately 20 miles long, from the Natural Gas Pipe Line Company of America's 30-inch transmission line from Texas. The lateral also is used for withdrawal of gas from storage (see figure 10).

Table 9 gives a monthly summary of gas injections and withdrawals for 1960.

Table 9 - Cooks Mills Gas Storage, 1960
(in Mcf, as metered at 14.65 psia)

	Injection	Withdrawal	Inventory
December, 1959			1,997,616
January, 1960	-	240,511	1,957,105
February	-	60,703	1,696,402
March	-	909	1,695,493
April	-	173	1,695,320
May	-	78	1,695,242
June	-	19	1,695,223
July	427,108	-	2,122,331
August	-	16	2,122,315
September	-	92	2,122,223
October	-	377	2,121,846
November	-	588	2,121,258
December	-	885	2,120,373

Crescent City Dome

Operator: Northern Illinois Gas Company.

Location: Between Crescent City and Watseka, Iroquois County.

Geologic Investigations: Following an examination of well cuttings in the files of the Illinois State Geological Survey, Northern Illinois Gas Company commissioned a gravity survey in Iroquois County in the spring of 1959. A gravity anomaly was found just west of Watseka. In June, 1959, a small drilling rig was moved into the area, and by February, 1960, some 22 structure test wells had been completed, 20 of which penetrated the Galena Limestone. Further drilling was carried on until by October 26, 1960, about 70 structure test wells had been completed. A structure contour map of the Crescent City Dome based on the data from drilling is shown in figure 15.

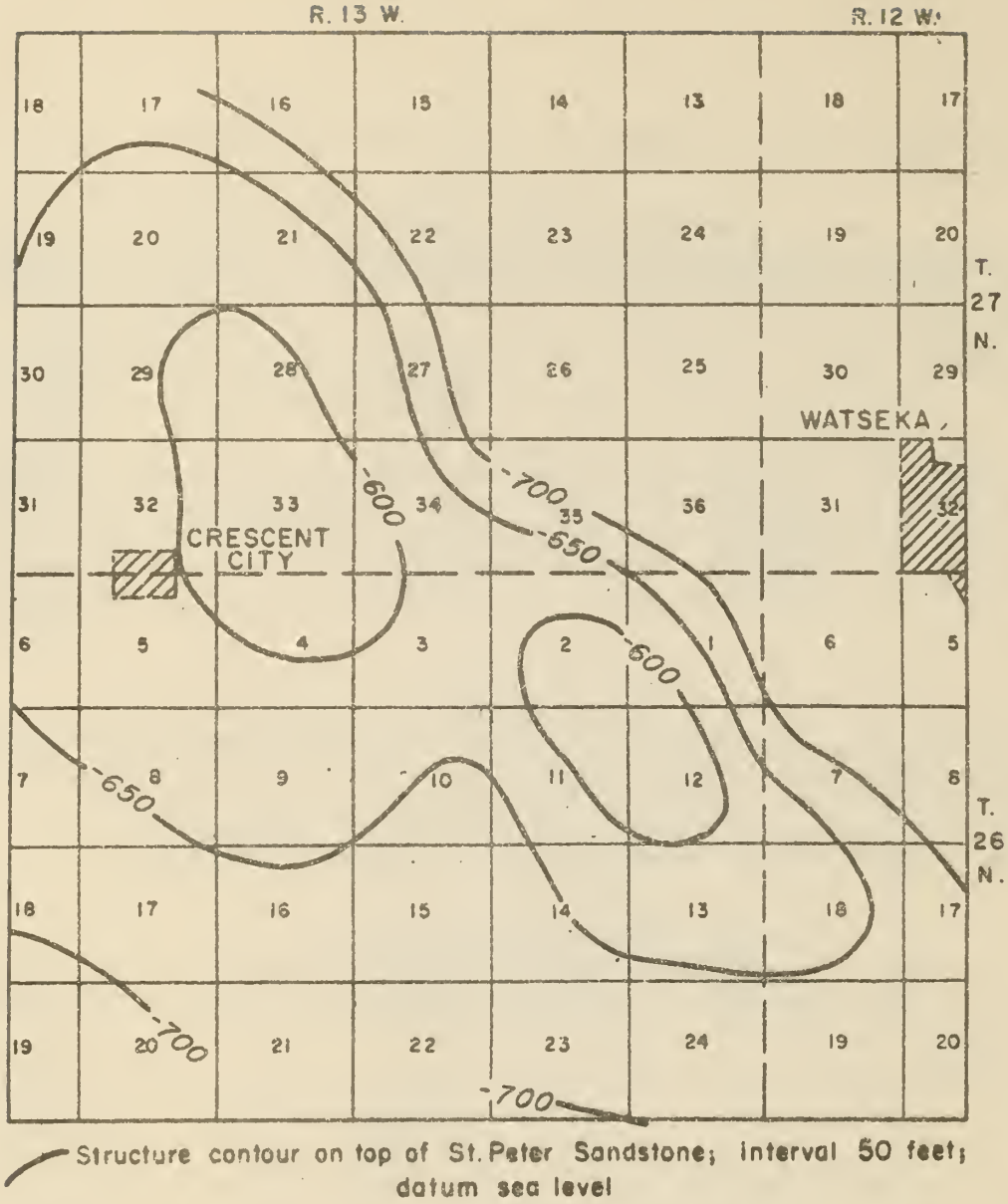


Figure 15. Crescent City Dome, Iroquois County, Illinois (after map by Northern Illinois Gas Company, October 26, 1960)

During July, August and September, 1960, the Illinois Commerce Commission held four hearings on the application of the Northern Illinois Gas Company for a certificate of convenience and necessity to test, develop, operate, and maintain an underground gas storage operation in the Crescent City area, Iroquois County. The case was still pending at the end of 1960.

Waverly Dome

Operator: Panhandle Eastern Pipeline Company.

~~Location: Morgan County, Illinois, Southeast Township, Township 13 North, Range 8 West.~~

Geologic Investigations: A structure map of Pennsylvanian strata in the vicinity of Jacksonville, published in 1923, (Collingwood, fig. 2, p. 21) shows an anticlinal nose trending southwest-northeast in Township 12 North, Range 8 West, and Range 7 West. During succeeding years, deeper drilling found some gas and oil shows in Devonian strata. The structure of the Waverly Dome is shown in figure 16.

In the early 1950's, the Panhandle Eastern Pipeline Company acquired gas storage rights and in 1954, began injecting gas into the St. Peter Sandstone, which in this area contains salt water. The record of amounts of gas injected by months and by years is shown in table 10.

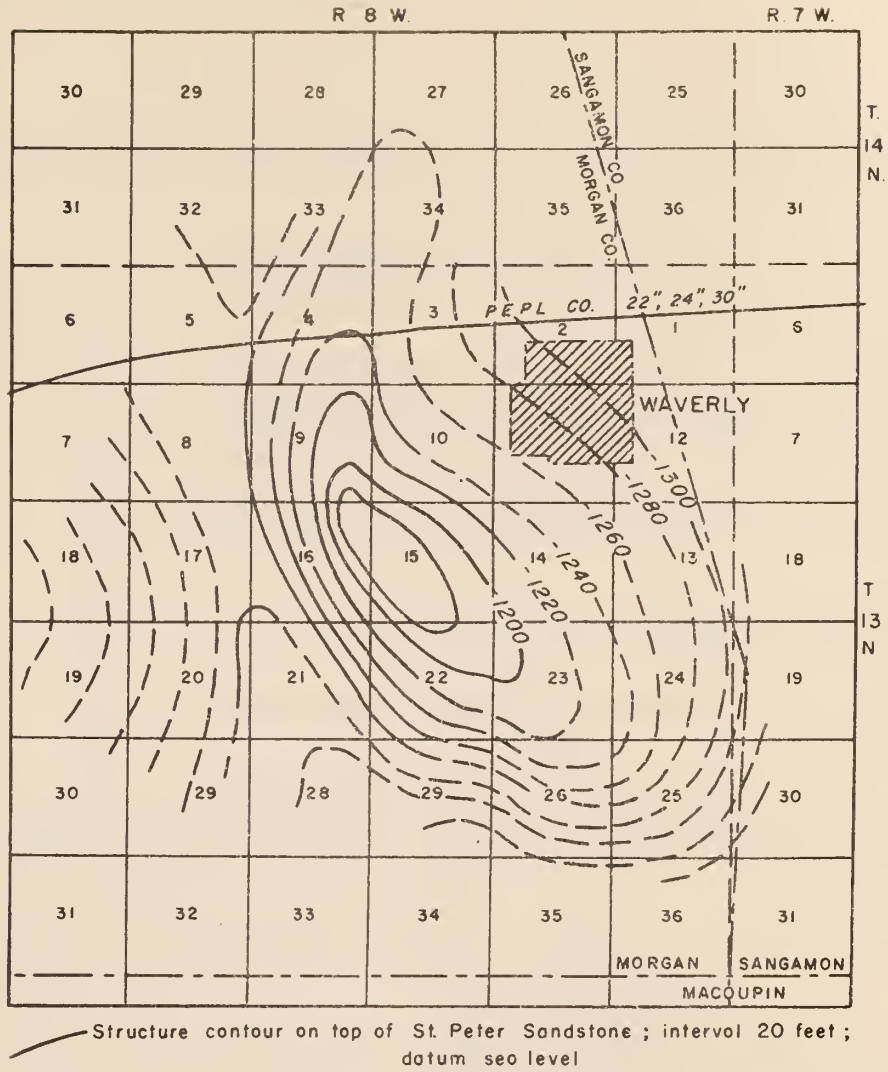


Figure 16. Structure of the top of the St. Peter Sandstone, Waverly Dome, Morgan County, Illinois (after map by Panhandle Eastern Pipeline Company)

Table 10 - Waverly Gas Storage Inputs
(In Mcf)

	1954	1955	1956	1957	1958	1959	1960
January			0	0	0	0	0
February		0	0	0	22,043	0	0
March		0	0	0	90,236	0	0
April	178,589	0	0	65,243	304,492	0	0
May	474,908	0	0	87,,169	232,521	0	0
June	555,877	0	33,796	85,328	197,988	0	0
July	529,266	0	84,081	199,866	186,775	0	0
August	104,367	0	91,492	237,156	191,353	0	0
September	149,766	0	122,210	201,495	182,842	0	0
October	0	0	166,499	198,674	188,458	0	0
November	0	0	64,705	180,216	148,212	0	0
December	0	0	0	52,281	0	0	0
Total	1,992,773	0	562,783	1,307,428	1,744,920	0	0

To date, there is no record that any of the injected gas has been recovered. A certificate application for authority to conduct productivity testing operations is in the hands of the Federal Power Commission.

Gillespie Gas Storage Field

Operator: Illinois Power Company.

Location: About two miles east of Gillespie village, Macoupin County.

History: The Gillespie Benld Gas Field was discovered in 1923 and was abandoned in 1935 after producing a total of approximately 136 million cubic feet of gas from a Pennsylvanian sandstone lens at the approximate depth of 540 feet. On September 9, 1958, the Illinois Commerce Commission granted to Illinois Power Company a certificate of convenience and necessity for the development, construction, operation, and maintenance of a natural gas storage reservoir in the depleted gas field.

The location of wells for injection and withdrawal of gas and the thickness of gas sand in each well are shown in figure 17.

The amounts of gas injected and withdrawn by months during 1960 are given in table 11.

Table 11 - Gillespie Gas Storage

1960	Injected Mcf	Withdrawn Mcf
Jan.	1,031	1,164
Feb.	0	12,029
March	18,193	14,164
April	6,852	396
May	1,977	0
June	0	0
July	0	0
Aug.	0	0
Sept.	933	0
Oct.	4,832	1,962
Nov.	0	24
Dec.	3,308	259
Total	37,126	29,998

The total amount of gas injected into the Gillespie Storage Reservoir in 1958 was 100,000 Mcf and for 1959, it was 43,531 Mcf. The amount withdrawn in 1959 was 10,423 Mcf. The amount injected in 1960 was 37,126 Mcf and the amount withdrawn was 29,998 Mcf.

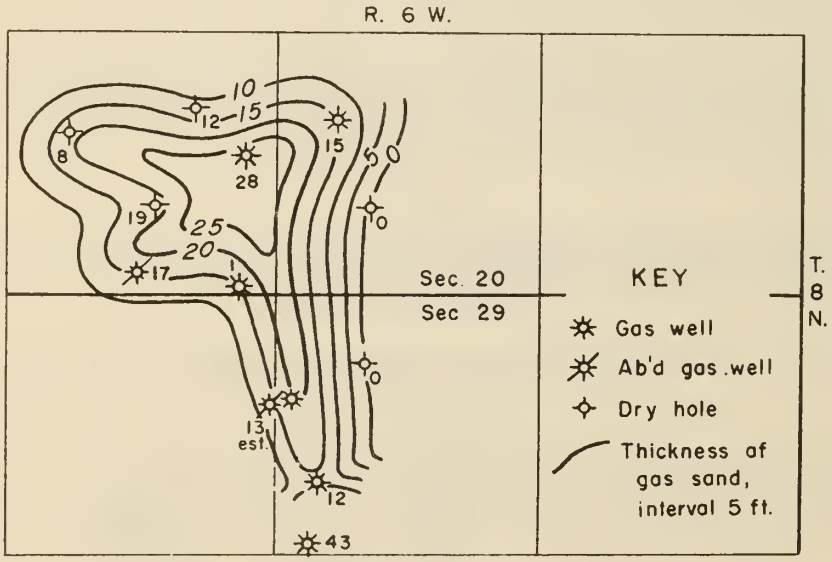


Figure 17. Gillespie Gas Storage Field, Macoupin County, Illinois (after map by Illinois Power Company, August 28, 1957; revised September 8, 1960)

St. Jacob Field

Operator: Mississippi River Fuel Corporation.

Location: Southeast part of Madison County about 24 miles east of East St. Louis.

History: The St. Jacob Oil Pool was discovered in 1942. Up to the end of 1959, some 53 producing wells had been drilled, of which 40 were still producing at the end of 1959. Production is from the Trenton

Limestone at the approximate depth of 2,260 feet. A structure map of the St. Jacob Field is shown in figure 18 by contours on top of the Trenton Limestone.

On the crest of the south dome, the top of the St. Peter Sandstone is at a depth of 2,850 feet and is approximately 100 feet thick. Six wells have been drilled into the St. Peter Sandstone. Based on tests of cores, total storage capacity of the St. Peter reservoir in the south dome has been estimated at 33 billion cubic feet. The capacity of the north dome is less.

An application for authorization to construct an 18-inch service pipeline, 95 miles long, from the Trunkline Gas pipeline at Johnsonville to the St. Jacob Storage Field is before the Federal Power Commission. This line will continue west from the storage field to St. Louis. It will connect with Illinois Power Company and Laclede Gas Company lines.

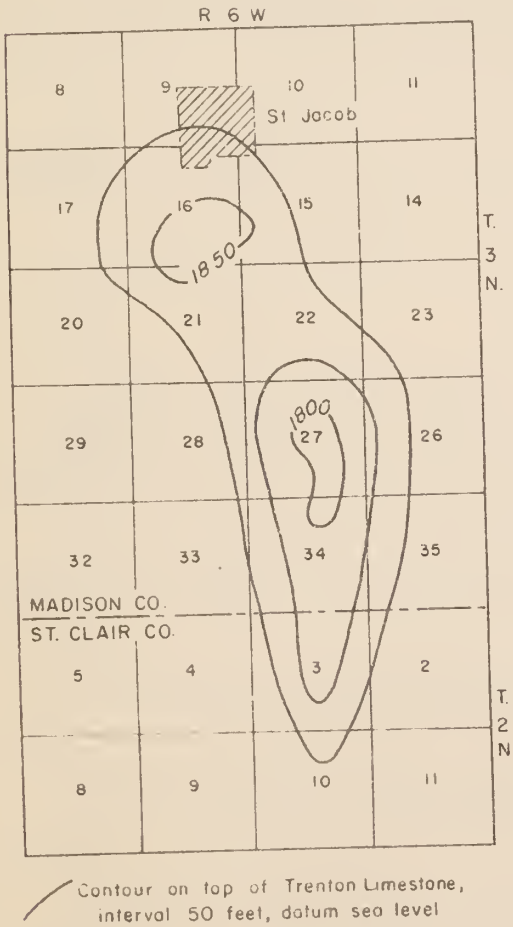
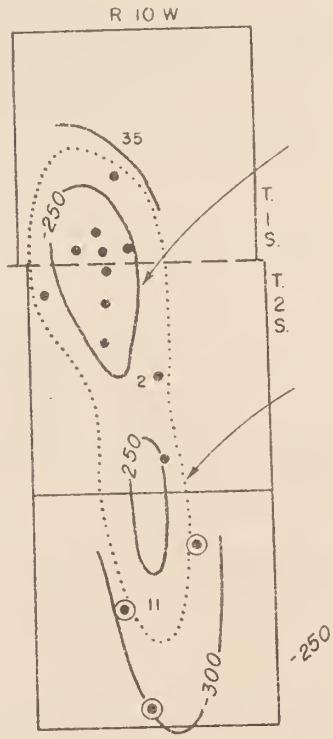


Figure 18. St. Jacob Gas Storage Field (after map by Mississippi River Fuel Corporation, January 25, 1960)



Calculated areal extent of St. Peter gas bubble when storage is full to leak point.

Calculated areal extent of Roubidoux-Gasconade gas bubble when storage is full to leak point.

KEY

Structure contour on top of St. Peter Sandstone, interval 50 ft., datum sea level.

• Gas input and withdrawal well.

⊙ Observation well.

Figure 19. Waterloo Field, Monroe County, Illinois (after map by Ball Associates, August, 1957, by courtesy of Mississippi River Fuel Corporation)

Waterloo Storage Field

Operator: Mississippi River Fuel Corporation.

Location: Monroe County, 15 miles south of East St. Louis.

History: The Waterloo Oil Pool was discovered in 1920 and was abandoned in 1930. Production was from Trenton Limestone at the approximate depth of 410 feet. The pool was revived in 1939 and was converted to gas storage in 1951. Eleven injection and withdrawal wells, of which eight are in use, were drilled into the Roubidoux (New Richmond) and Gasconade (Oneota) formations of Ordovician age to the depth of 1,450 or 1,500 feet.

The structure is a fairly sharp anticline trending slightly west of north with a closure of approximately 100 feet on the top of the St. Peter Sandstone (figure 19). The succession of formations and their thicknesses are shown for a location on top of the structure by the following summary sample-study log of a stratigraphic test well.

Mississippi River Fuel Corporation A-15 A. J. Theobald, SW-SE-SW.
Section 35, Township 1 South, Range 10 West, Monroe County
Drilled March, 1952

	Thickness (ft.)	Depth (ft.)
No samples	200	200
Ordovician System		
Cincinnatian Series		
Maquoketa Formation		
Shale, dolomitic	170	370
Dolomite, argillaceous	20	390
Mohawkian Series		
Kimmswick Formation		
Limestone	30	420
Dolomite, calcareous	70	490
Decorah Formation		
Limestone, little sand and shale at base	30	520
Plattin Formation		
Limestone, dolomitic, cherty	190	710
Joachim Formation		
Limestone	20	730
Dolomite, calcareous; little green shale	154	884
Glenwood Formation		
Sandstone, shaly	17	901
Chazy Series		
St. Peter Formation		
Sandstone	52	953
Everton Formation		
Sandstone and dolomite interbedded	127	1,080
Prairie du Chien (Canadian) Series		
Powell (Shakopee) Formation		
Dolomite, sandy; little shale	156	1,236
Cotter (Shakopee) Formation		
Dolomite, sandy	62	1,298
Jefferson City (Shakopee-New Richmond) Formation		
Dolomite, cherty	60	1,358
Roubidoux (New Richmond) Formation		
Dolomite, cherty, slightly sandy	89	1,447
Gasconade-Van Buren (Oneota) Formation		
Dolomite, cherty	358	1,805
Cambrian System		
St. Croixan Series		
Emminence (Trempealeau) Formation		
Dolomite, vuggy, cherty	125	1,930

	Thickness (ft.)	Depth (ft.)
Potosi (Trempealeau) Formation		
Dolomite-vugs lined with quartz and calcite; some banded chert	325	2,255
Derby-Doe Run (Franconia) Formation		
Dolomite, argillaceous	135	2,390
Davis (Franconia) Formation		
Dolomite, sandy; some shale and glauconite	86	2,476
Bonne Terre (Eau Claire) Formation		
Dolomite, sandy, glauconitic	274	2,750
Precambrian		
Granite, red	17	2,767
Total Depth		2,767

At the beginning of 1959, 449,723 Mcf of gas was in storage. Total injection during 1959 was 1,185,904 Mcf and total withdrawn was 1,160,469 Mcf, with a net increase of gas in storage of 25,435 Mcf. The maximum withdrawn in one day was 20,614 Mcf. The amount of gas in storage at the end of 1960 was 206,000 Mcf. The maximum pressure that could be used without leakage was 550 psi.

Because of the small capacity of the reservoir, it was not practical for seasonal storage, but it serves a useful function for daily injections and withdrawals which take care of the night and day variations in demand. In this way, it serves in the manner of a surge tank.

Gas for injection into the Waterloo Storage Field is brought from the company's trunk pipeline, one and one-half miles to the west, by a six-inch pipeline.

Freeburg Gas Storage Field

Operator: Illinois Power Company, 500 South 27th Street, Decatur, Illinois.
Location: St. Clair County, eight miles southeast of Belleville.
Geologic Information: The Freeburg Pool was discovered in 1956 as a natural gas field with no commercial production. After a detailed drilling program, the Illinois Power Company exercised its option to purchase the gas in place and the storage rights.

The exploration program included 21 core tests around the perimeter and the drilling of 24 wells which were completed in a manner that would permit their use as injection or producing wells. These wells provided the basic data necessary to estimate the amount of gas in place and the feasibility of underground storage.

An additional 44 wells were drilled during 1959 and 1960 and completed in a similar manner to finish the development program. Five observation wells were drilled around the perimeter of the storage area during this period for a total of 68 service wells and five observation wells in the entire project.

The gas reservoir is the Cypress Sand, which is of the Chester Group and Mississippian in age. The local structure of the sand body is monoclinal, shaling out to the north, west and south. The usual regional dip to the east is present, and the sand thickens and become saturated with water.

The maximum thickness of the Cypress Sand in the gas productive area of some 2,400 acres is 47 feet, and the top is 308 feet from the surface at its highest point. The "caprock" or barrier to migration of oil is a 16- to 28-foot shale between the top of the Cypress Sandstone and the bottom of the Barlow Limestone.

The open-flow potential of the wells has averaged 2,000 Mcf per day with a maximum of 4,500 Mcf per day. The bottom-hole pressure was 165 psi. The volume of gas in place, reduced to atmospheric pressure, was estimated to be 6,400,000 Mcf.

Figure 20 is a contour map of the base of the Beech Creek (Barlow) Limestone (Meents, 1959).

Operation: To supplement the gas in place, additional gas is purchased from Mississippi River Fuel Corporation during summer months and, as the demand will allow, during the rest of the year.

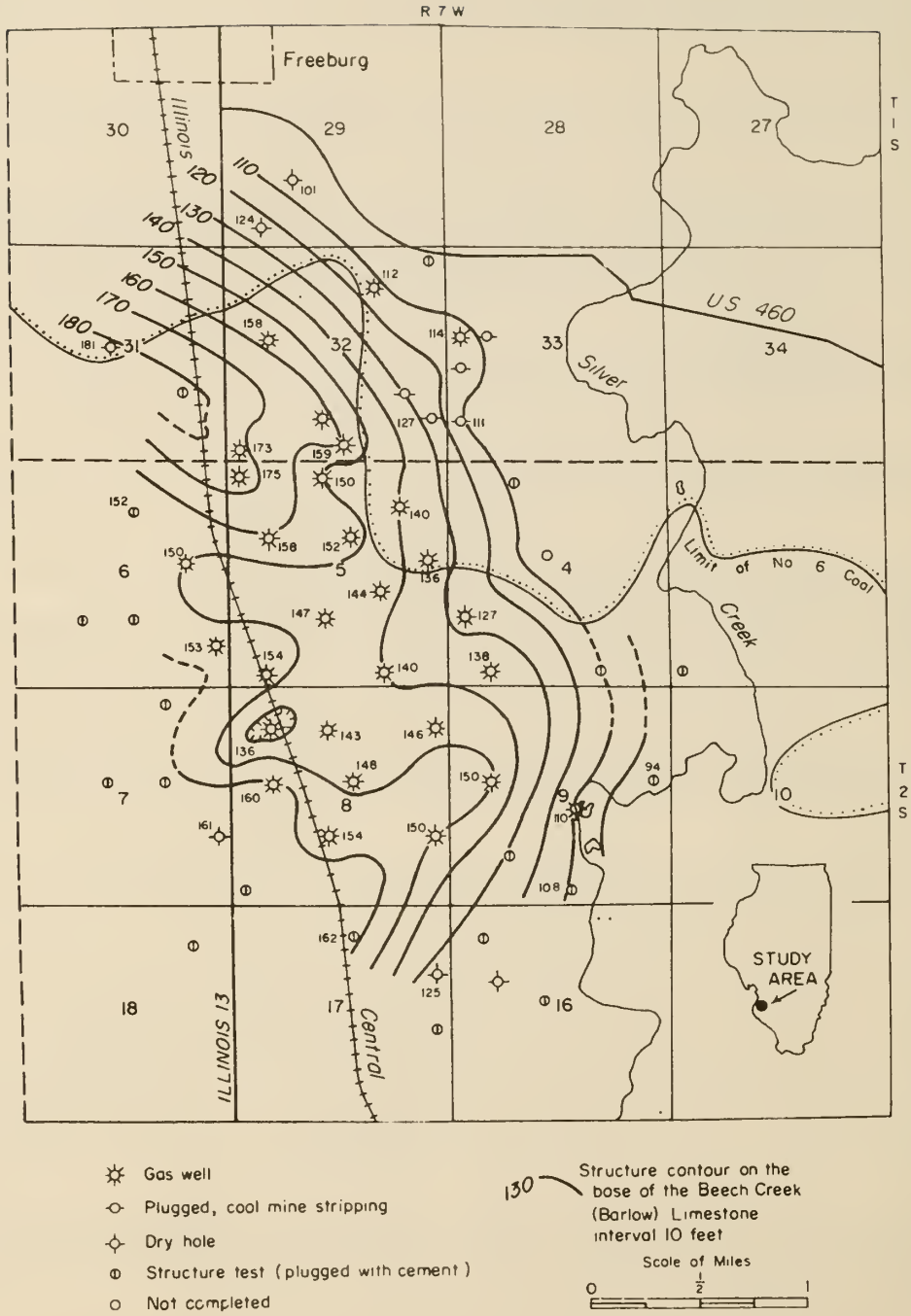


Figure 20. Structure of base of the Beech Creek (Barlow) Limestone at Freeburg Gas Pool (Illinois Geol. Survey Circ. 272, fig. 3)

Injection was commenced during August, 1959, and it is anticipated that a maximum of 15,000 Mcf per day at a pressure of 180 psi will be injected through the 68 wells. The ultimate withdrawal rate is expected to be 30,000 Mcf per day.

In addition to installing a field gathering and injection system and dehydrating and compressor facilities, five miles of 18-inch and nine miles of 14-inch line have been laid from the storage area to the existing distribution system at Belleville. This new line has been designed also to handle gas from the proposed storage project in the Tilden Field, which is discussed in this report.

The cost of storage gas at Belleville, when demand charges are considered, is about equal to that of the same volume of gas if it were available and could be purchased by Illinois Power Company at existing rates.

Table 12 gives the injection and withdrawal volumes since initiation of the project.

Table 12 - Freeburg Gas Storage

	Injection Mcf	Withdrawal Mcf
1959	169,985	180,643
Jan. 1960	22,446	32,714
Feb.	28,204	215,877
March	0	88,900
April	115,266	0
May	98,128	1,229
June	0	0
July	0	0
Aug.	25,580	0
Sept.	112,349	0
Oct.	32,059	4,518
Nov.	34,666	7,363
Dec.	25,757	111,101
Total	664,440	642,345

Net balance in storage Jan. 1, 1961, was 22,095 Mcf.

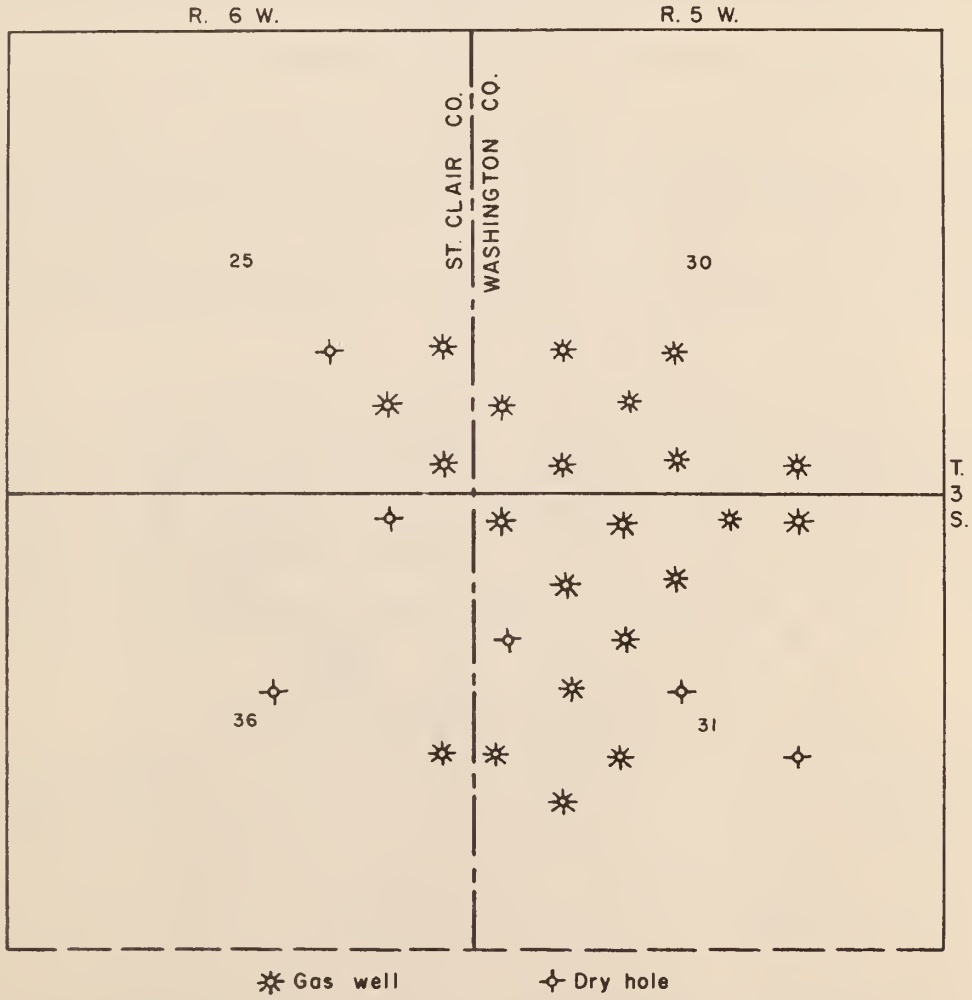


Figure 21. Tilden North Field, gas storage in lenticular Cypress Sandstone. (Data from Illinois Power Company, August, 1955)

North Tilden Gas Storage Field

Operator: Illinois Power Company, 500 South 27th Street, Decatur, Illinois.

Location: At the junction of St. Clair, Washington and Randolph Counties, 23 miles southeast of Belleville and 15 miles southeast of the Freeburg Storage Project.

Geologic Information: The North Tilden Pool was discovered in 1957 as a natural gas field with no commercial oil production. It was purchased under option by the Illinois Power Company, but the exploratory program is still being conducted, and little information is available for publication at this time.

To January 1, 1961, 24 wells have been drilled and completed as both injection and producing wells.

The gas reservoir is the Cypress Sand, which is of the Chester Group and Mississippian in age. The local structure is monoclinal with a shale-out to the north, west, and south. The sand body has the usual regional dip to the east and becomes water saturated.

Within the present projected storage area of about 500 acres, the Cypress has a maximum thickness of 33 feet and is 785 feet from the surface at its highest point. The "caprock" or migration barrier is the shale body between the top of the Cypress and the bottom of the Barlow Limestone. The average thickness of this formation is 20 feet.

The open flow potential, at the bottom-hole pressure of 330 psi, has averaged 6,000 Mcf per day with a maximum of 11,500 Mcf. Since the project is still under development, the amount of gas in place has not yet been determined.

Figure 21 is a map of the Tilden North storage area showing the location of injection and withdrawal wells in the Cypress Formation.

Operation: When operation of the project is begun, it is expected that 15,000 Mcf per day will be injected at 360 psi. The ultimate withdrawal rate is estimated to be 30,000 Mcf per day.

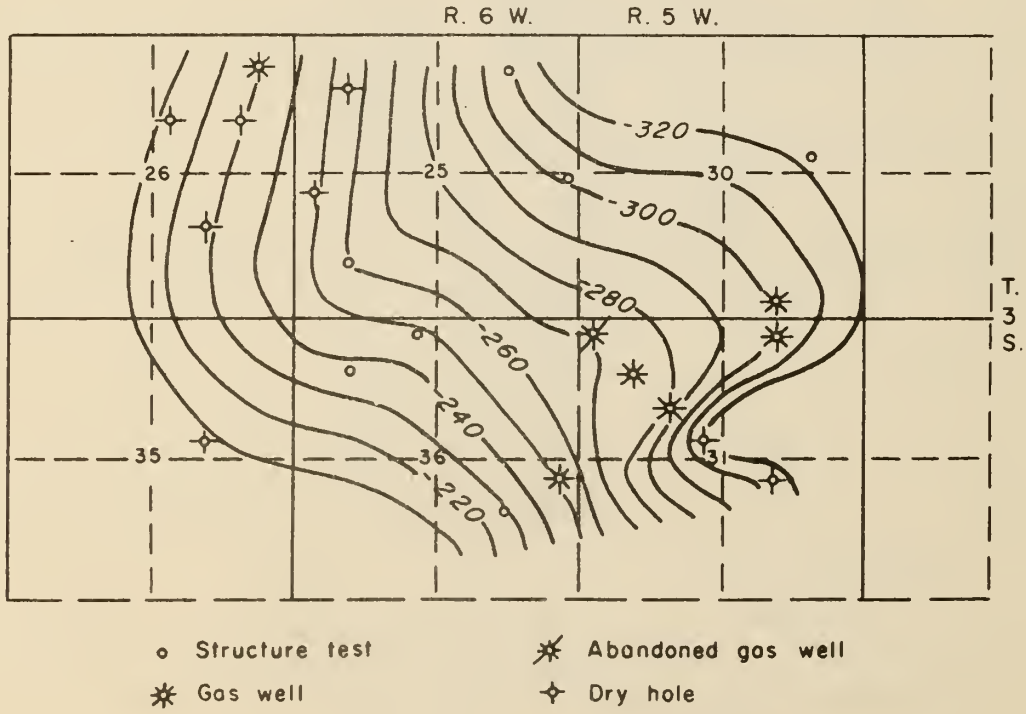


Figure 22. Structure of top of Cypress Sandstone in Tilden North Field in St. Clair, Washinton, and Randolph Counties, Illinois (after map by James A. Lewis Engineering, Inc.)

In addition to the field gathering and injection system, and dehydrating and compressing facilities, 15 miles of 16-inch line will be laid from North Tilden to the Freeburg Field. This will allow the use of the new Belleville-Freeburg line to serve the North Tilden operation.

The total investment in the North Tilden project is expected to be some $4,500,000 and will have about the same economic justification as the Freeburg project.

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INDIANA

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Indiana Department of Conservation

Abstract

Underground gas storage has proved to be economically possible in the State of Indiana. Eleven storage fields are in use, and the search for other possible storage is being continued. Storage reservoirs range in age from Middle Ordovician to Early Pennsylvanian. Deeper possible storage in the sandstones and dolomites of the Late Cambrian and Early Ordovician should not be overlooked. The southwestern part of Indiana, because of the large amount of drilling for oil and gas that has taken place, is probably the most likely area in which to look for future storage facilities.

Introduction

Basic facts dictate the expansion of underground storage of natural gas in Indiana. The State's lack of significant commercial gas production and the presence of large urban and industrial areas both within and near its borders make the storage of gas economically desirable. The annual delivery capacity of large transmission lines which cross or terminate in Indiana (figure 23), and which carry gas from the Gulf Coast to the Midwest and eastern part of the United States, would be increased materially by underground gas storage facilities in Indiana.

There are 11 storage areas in operation in Indiana (figure 23 and table 13). Four more areas are being tested to determine whether or not storage may be accomplished.

Natural Gas Production

Gas is being produced or has been produced from 16 different stratigraphic units ranging in age from Ordovician to Pennsylvanian (figure 24). Indiana does not have significant commercial gas production at the present time. Figures 25 and 26 show the locations of all producing and abandoned gas fields in Indiana. Production from nearly all the active fields is used in farm homes or in adjacent small communities. Few, if any, completely reliable gas production figures by field or area are readily available.

Gas production in Indiana began with the discovery of gas in the Trenton Field (figure 26) in the east-central part of the State in the middle 1880's. Production was from the Trenton Limestone of Middle Ordovician age. At this time one of the greatest wastes of natural gas took place, and as a consequence the earliest conservation laws in Indiana were written. Many towns burned huge flambeaus in order to

[1] Now Director of Oil and Gas Conservation, Commonwealth of Kentucky, Lexington.

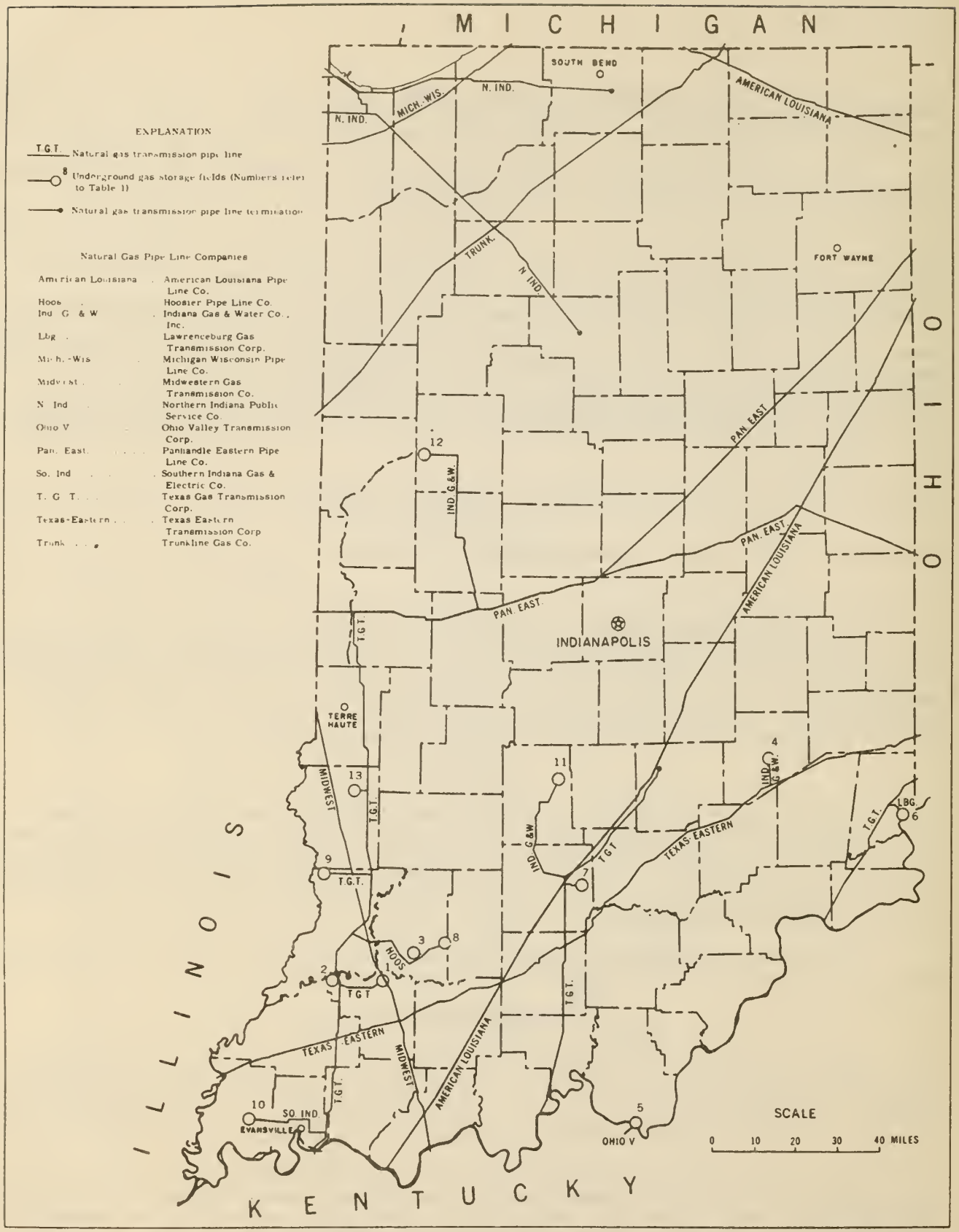


FIGURE 23. MAP OF INDIANA SHOWING LOCATION OF MAJOR NATURAL GAS TRANSMISSION PIPELINES AND UNDERGROUND GAS STORAGE FIELDS

Table 13. Summary of Natural Gas Storage Fields in Indiana

Project	Operator	County	Location Section	Location Township	Location Range	Storage stratigraphic unit	Character of trap	Number of storage wells 4-11-60	Date of first storage	Total reservoir capacity (MCF)	Working reservoir capacity (MCF)
1. Alford	Texas Gas Transmission Corp.	Pike	17,18,19,20, 29,30	1N	7W	Cypress Ss.[1]	Stratigraphic trap	43	1951	2,469,300	969,300
2. Giro East	Texas Gas Transmission Corp.	Pike	16,17,20,21, Survey 9	1N	9W	Cypress Ss.[1]	Stratigraphic trap			Experimental	
3. Glendale North	Hoosier Pipe Line Corp.	Daviess	15,16	2N	6W	Cypress Ss.[1]	Stratigraphic trap	4	1956	-----	200,000
4. Greensburg	Indiana Gas & Water Co.	Decatur	1,2,11,12,13, 14,15 6,7 31,32	9N 9N 10N	9E 10E 10E	Trenton Ls.	Porosity development	59	1950	1,000,000*	150,000*
5. Laconia	Ohio Valley Transmission Corp.	Harrison	4,5,8,9,15,16	6S	4E	Devonian and Silurian lss.	Anticline	27	1946	3,500,000[x]	2,000,000[x]
6. Lawrenceburg	Lawrenceburg Gas Co.	Dearborn	15	5N	1W	Cynthiana Fm.	-----	1		No data available	
7. Leesville	Texas Gas Transmission Corp.	Lawrence	6,7,17,20,21, 28,29	5N	2E	Geneva Dol.	Faulted anticline			Experimental	
8. Loogootee	Hoosier Pipe Line Corp.	Daviess	34	3N	5W	Bethel Fm.	Stratigraphic trap	4	1951	-----	105,000
9. Oaktown	Texas Gas Transmission Corp.	Knox	11,14,15, Locations 120,174, 261	5N	10W	Pennsylvanian ss.	Stratigraphic trap	26	1944	1,031,000	610,710
10. Oliver	Southern Indiana Gas & Elec. Co.	Posey	1,2,12	6S	13W	Pennsylvanian ss.	Stratigraphic trap	32	1954	2,887,500	1,036,040
11. Unionville	Indiana Gas & Water Co.	Monroe	7,8,17,18	9N	1E	Devonian ls.	Faulted anticline	9	1954	2,500,000*	1,204,000*
12. Westpoint	Indiana Gas & Water Co.	Tippecanoe	17,18,19 13,24, Burnett's Reserve 4 & 5	22N 22N	5W 6W	Devonian ls.	Anticline	25	1957	600,000*	203,000*
13. Wilfred	Texas Gas Transmission Corp.	Sullivan	30	9N	8W	Devonian ls.	Dome	13	1959	2,400,000	1,200,000

[1] Correlative of the Elwren Fm.
[x] Includes Kentucky portion of field
* As of Oct. 31, 1959

System	Series	Formation or group	Lithology*	Gas productive zones	Gas storage zones
Pennsylvanian	Conemaugh	undifferentiated	sh.,ss.,ls.,coal		
	Allegheny	undifferentiated	sh.,ss.,ls.,coal		
	Pottsville	undifferentiated	sh.,ss.,thin coal	X	X
Mississippian	Chester	Kinkaid	ls.,sh.		
		Degonia	ss.,sh.		
		Clore	ls.,ss.,sh.		
		Palestine	ss.,sh.	X	
		Menard	ls.,sh.		
		Waltersburg	ss.,sh.		
		Vienna	ls.,sh.		
		Tar Springs	ss.,sh.	X	
		Glen Dean	ls.,sh.		
		Hardinsburg	ss.,sh.	X	
		Golconda	ls.,sh.		
		Jackson[x](Big Clifty)	ss.,sh.	X	
		Barlow[x](Beech Creek)	ls.		
		Cypress[x](Elwren)	ss.,sh.	X	X
		Paint Creek	ls.,ss.,sh.	X	
		Bethel	ss.,sh.	X	
		Renault	ls.,ss.,sh.	X	
		Aux Vases	ls.,sh.,ss.	X	
	Meramec	Ste. Genevieve	ls.,sh.,ss.	X	
		St. Louis	ls.,sh.		
		Salem	ls.	X	
		Harrodsburg	ls.,sh.		
	Osage	Borden Group undifferentiated	slt.,sh.,ls.,ss.		
	Kinderhook	Rockford	ls.		
		New Albany	sh.	X	
Devonian	undifferentiated	undifferentiated	ls.,dol.	X	X
Silurian	undifferentiated	undifferentiated	ls.,dol.,sh.		X
Ordovician	Cincinnatian	undifferentiated	sh.,ls.		X
	Mohawkian	Trenton	ls.,dol.	X	X
		Black River	ls.,dol.	X	
	Chazyan	Joachim	dol.		
		St. Peter	ss.		
Cambrian	Canadian	Knox	dol.		
	St. Croixan	Eau Claire	slt.,sh.,ss.,dol.		
		Mt. Simon	ss.		
Precambrian					

*dol. - dolomite
ls. - limestone
ss. - sandstone
sh. - shale
slt. - silt
*Subsurface terminology

Figure 24. Chart showing Indiana stratigraphic sequence, gas producing zones, and gas storage zones.

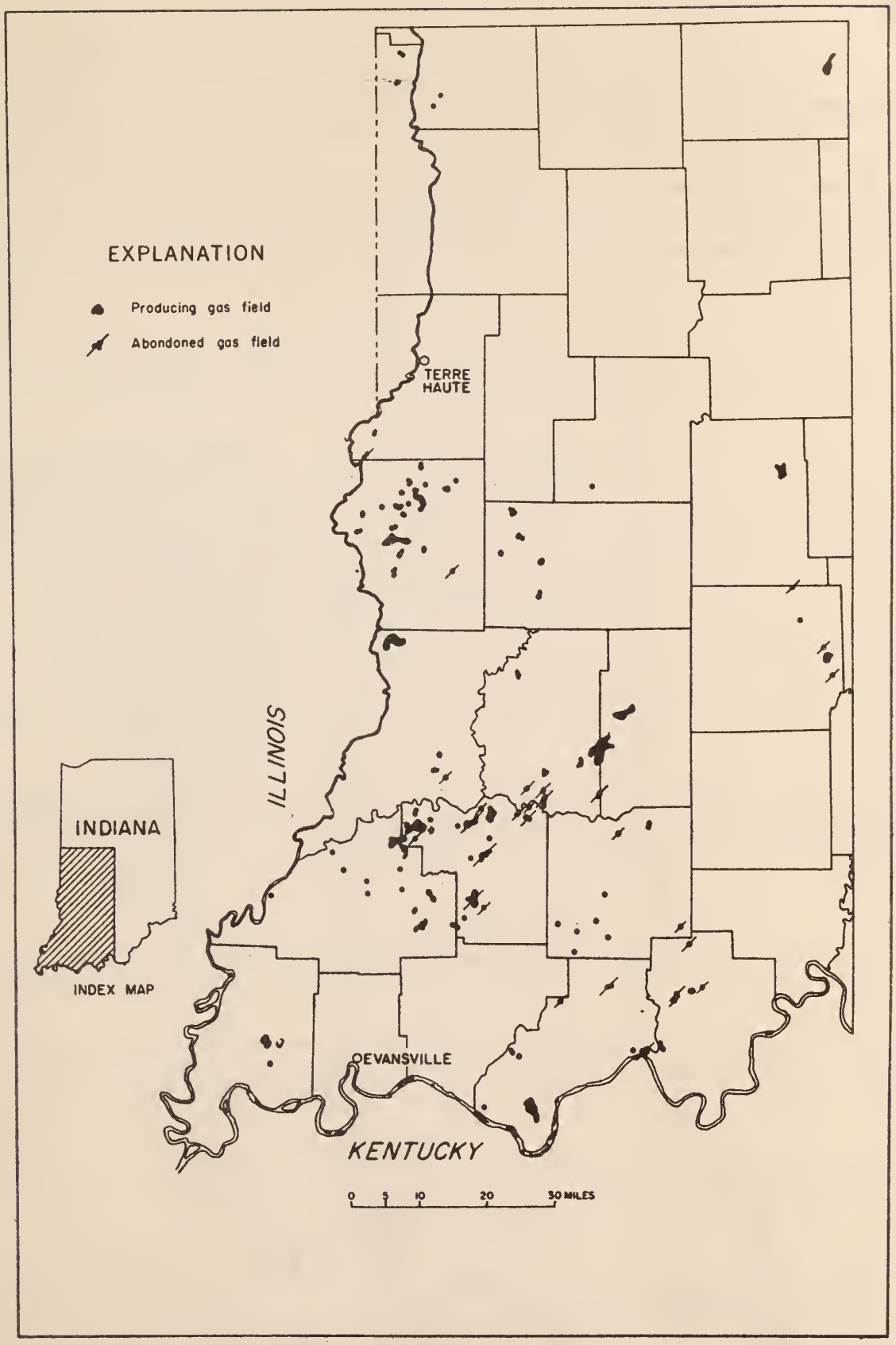


FIGURE 25. MAP OF SOUTHWESTERN INDIANA SHOWING LOCATION OF NATURAL GAS FIELDS

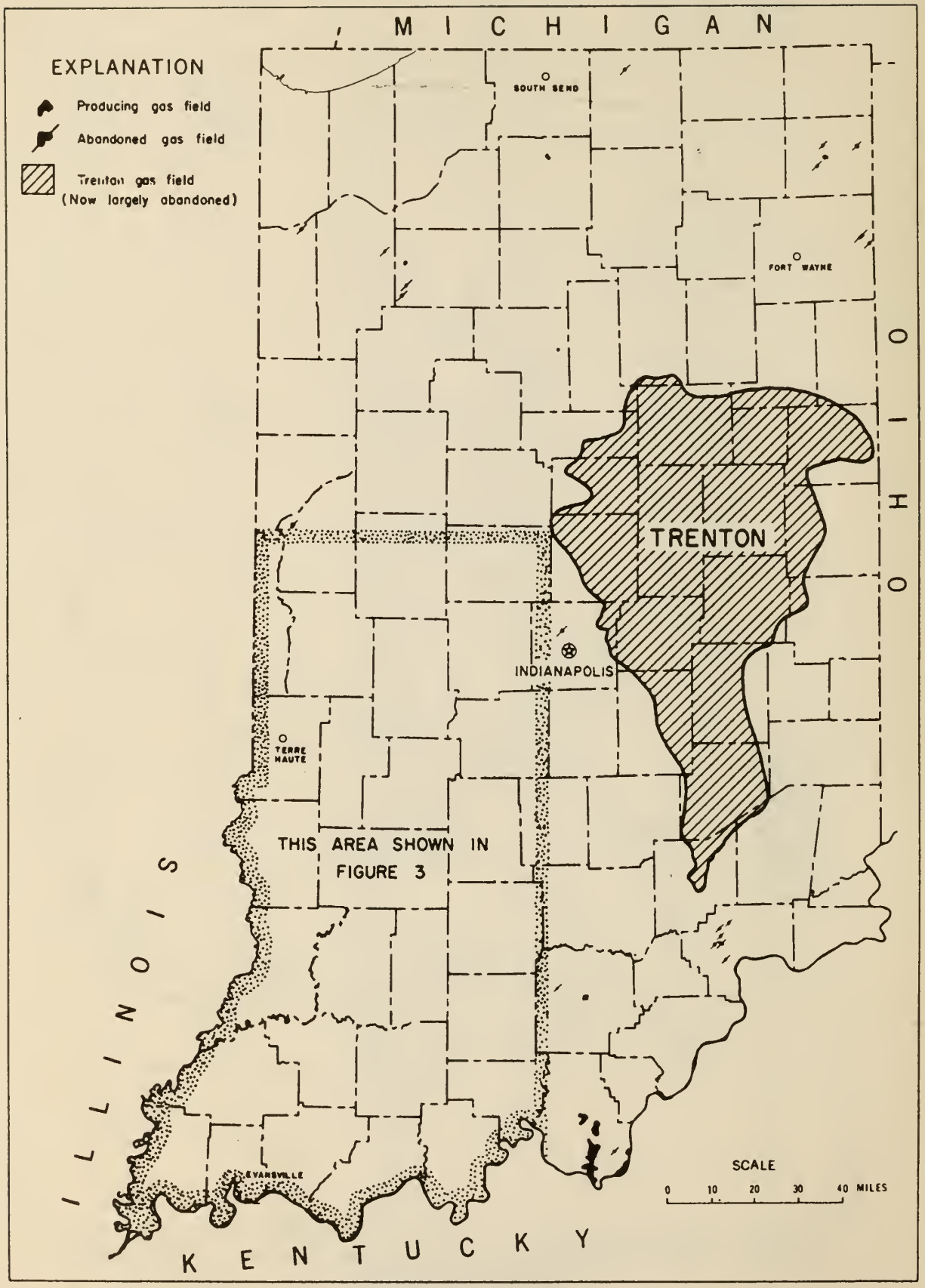


FIGURE 26. MAP OF INDIANA SHOWING LOCATION OF NATURAL GAS FIELDS

attract industry by showing them the immense energy portention available. As a result, the gas in many parts of the field was exhausted quickly, and what could have meant a great deal to the people of the state was callously wasted.

In the 1930's increased drilling for oil in southwestern Indiana, the Indiana portion of the Illinois Basin, resulted in the discovery of many relatively unimportant supplies of gas (figure 25). Gas in these fields is used to supply farms and small communities and in some places to supplement gas from pipelines that serve some of the larger cities. Many of the gas wells drilled only a few years ago have been abandoned.

Regional Geologic Conditions

Sedimentary bedrock in Indiana ranges in age from Late Cambrian to Late Pennsylvanian (see figure 27). The combined maximum thickness of these rocks is more than 12,000 feet. This thickness is present in the extreme southwest corner of the State.

Approximately five-sixths of the land surface of Indiana is covered by glacial material. Glacial drift is more than 525 feet thick in some places in northeastern Indiana.

Indiana lies in the stable east-central part of the North American continent, and the sedimentary bedrock is relatively flat lying. A large positive structure called the Cincinnati Arch extends from southeastern Indiana northward and northwestward to southern Wabash County and southern Miami County. Dips in this area are very low, and the direction of dip in many places is unpredictable.

The rocks dip westward and southwestward from the Cincinnati Arch toward the Illinois Basin. The dip increases from less than 10 feet per mile near the crest of the arch to as much as 50 feet per mile in the extreme southwestern part of Indiana. Northward from the arch, beds dip into the Michigan Basin at approximately 20 feet per mile. In northwestern and north-central Indiana, the Illinois and Michigan basins are separated by a positive structure, the Kankakee Arch, which is much like, but narrower than, the Cincinnati Arch.

Faults are rare in Indiana, but they have had some effect on storage fields (table 13). Faults are known in Dubois, Gibson, Lawrence, Monroe, Perry, Posey, and Spencer Counties. The Mount Carmel Fault in Lawrence and Monroe Counties has been accurately mapped by the Indiana Geological Survey. Abundant subsurface data available for the other counties listed permit accurate determination of the location of these structures.

Gas Storage

Basic subsurface geological data are available for three stratigraphic units in which gas storage is potentially possible (figure 28). These units include most of the producing horizons in Indiana's oil and gas fields.

The extreme southwestern part of Indiana is underlain by rocks of Pennsylvanian age at sufficient dept for storage purposes (area 1, figure 28). These rocks include many channel sandstones which at various places are oil and or gas reservoirs. Two of the presently active storage fields are in rocks of this age (table 13).

The Lower Pennsylvanian rocks consist of shales, sandstones, and thin coals. As mentioned, the sandstones are mainly of the channel type, and, therefore, abrupt lateral changes from thick porous sandstones to tight sandstones with considerable shale are common. Such changes with the proper associated structures form traps which may be used for storage purposes.

Southwestern Indiana also is underlain by rocks of Chester (Late Mississippian) age. These rocks have provided and will certainly provide other suitable storage fields (area 2, figure 28). The Chester rocks are made up of alternating shales, sandstones, and limestones. All the sandstones and some of the limestones are oil and gas reservoirs somewhere in their subsurface extent. Most of these reservoirs are small, but they are adequate for use as storage fields. The sandstones are of the bar and channel type, and, therefore, the traps are mainly stratigraphic with minor associated structures. Three of the storage fields now being used were formed in rocks of Chester age (table 13).

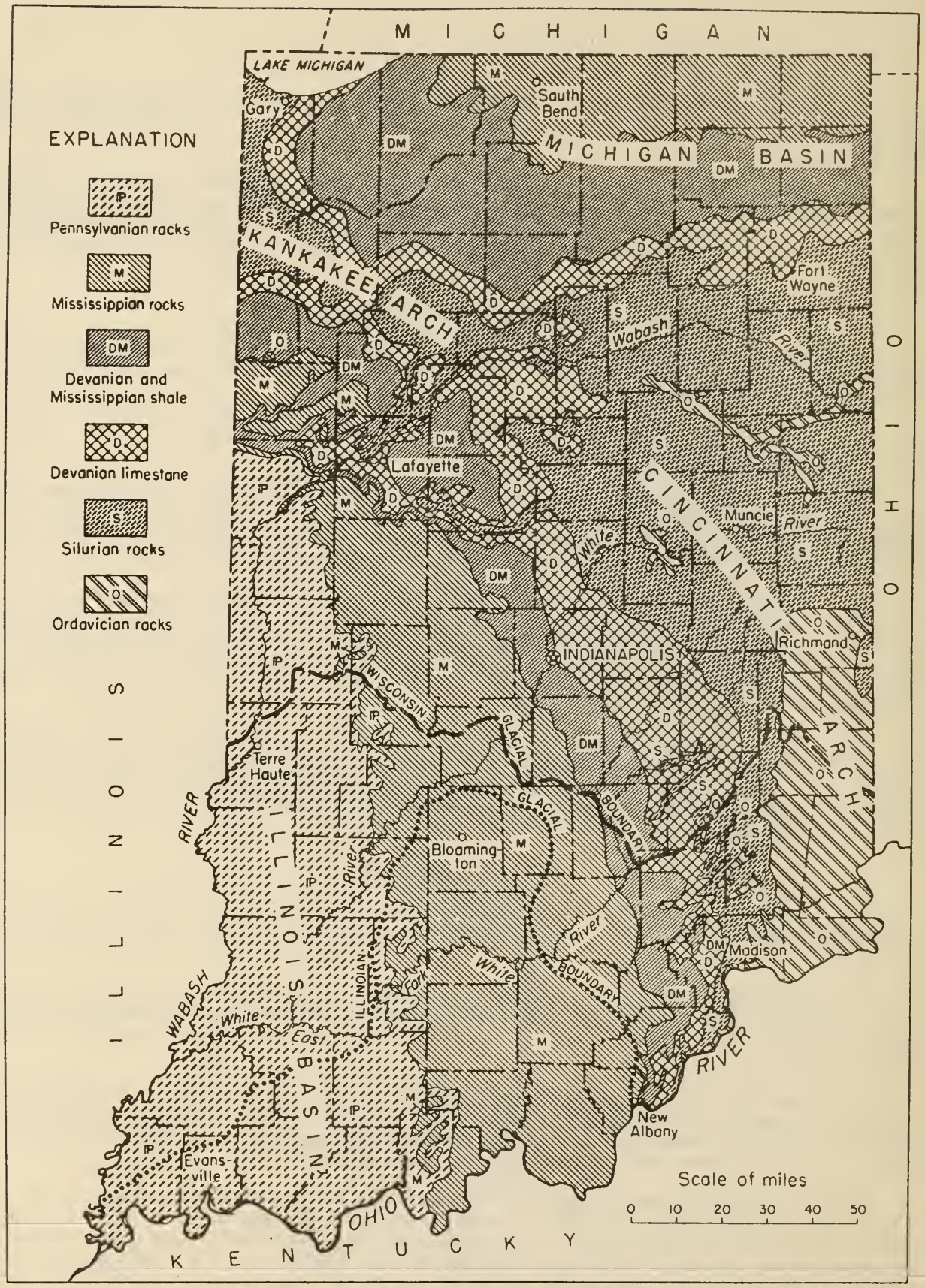


FIGURE 27. GENERALIZED BEDROCK MAP OF INDIANA

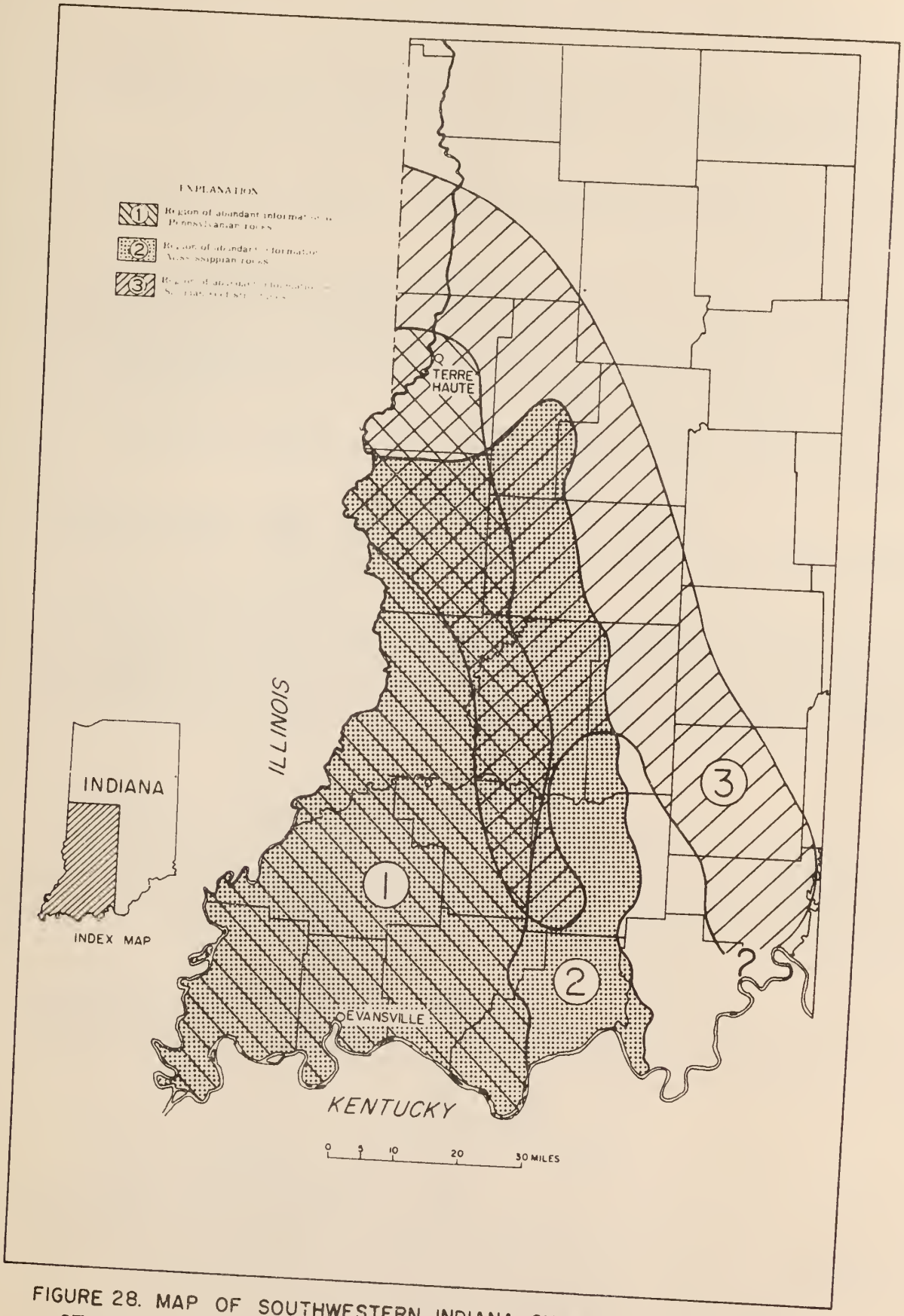


FIGURE 28. MAP OF SOUTHWESTERN INDIANA SHOWING POTENTIAL GAS STORAGE REGIONS IN WHICH ABUNDANT INFORMATION IS AVAILABLE

North and northeast of the stratigraphic units previously described is another rock configuration which provides good storage potential (area 3, figure 28). Throughout this outlined area the larger and well-defined Silurian reef structures occur. Although the reefs themselves have not been considered as storage reservoirs, younger rocks overlying these structures are being used (table 13).

Silurian reefs are known to occur both north and northeast of the outlined area, but these reefs are smaller and are not so well defined by subsurface data, because no hydrocarbons have been produced from the rocks overlying them. They cannot be ignored, however, as possible potential reservoir structures.

Rocks of Late Cambrian and Early Ordovician age underlie all Indiana. These rocks may afford sites for underground gas storage. A map (figure 29) contoured on the top of the Knox Dolomite is included to give an indication of the depths and regional attitude of these rocks. This rock sequence is made up of sandstones, dolomites, shales, and siltstones and is 2,000 feet or more thick. Owing to the depth of these rocks and their lack of commercial oil or gas production, information concerning them is relatively meager. They should not be ignored entirely, however, when storage is being considered.

Rocks of other ages (figure 24) are being used for gas storage. The rock units described in this report, however, are the ones which offer the best potential for the least amount of investigation.

Regulations Affecting Storage Projects

The State of Indiana has one bill specifically affecting gas storage projects. The bill was passed by the State Legislature in 1959. A copy of this recent law is included at the end of this report as appendix A.

The Oil and Gas Law in its present form was passed by the State Legislature in 1951. This law and the Rules and Regulations of the Department of Conservation as promulgated under the law affect gas storage projects only to the same extent that all drilling in the state is affected. The 1951 law requires permits for new storage wells and requires submission of certain records. Regulations concerning abandonment and proper plugging of gas storage wells also are included in this act. The regulatory agency which administers these laws is the Division of Oil and Gas of the Indiana Department of Conservation.

Conclusions

Indiana's geographical and industrial position has necessitated the development of underground storage fields for natural gas, and all indications point to the development of additional storage fields. Formations within all the Paleozoic systems are being used or may possibly be used for gas storage. Because of the character of the bedrock and the relatively intense drilling for oil and gas, the southwestern part of the state offers the best geologic possibilities for storage. Small isolated traps will be found in other areas in the state, and certainly the rocks of Early Ordovician age and older rocks should not be overlooked.

All information presented here is of necessity regional. Additional information on the geology of potential gas storage areas is available at the Geological Survey, Indiana Department of Conservation, Bloomington, Indiana. Here is to be found, among other types of information, the most complete set of drilling records available for the State of Indiana. Interested parties should visit the Geological Survey to make use of this material.

APPENDIX A

Senate Enrolled Act No. 190

"An act authorizing certain persons, firms or corporations, including municipal corporations, engaged in rendering gas service directly or for resale to the public to appropriate and condemn rights in lands, improvements, subsurface strata or formations in lands, and easements in lands and subsurface strata in lands for the purpose of the underground storage of gas, and declaring an emergency:

Be it enacted by the General Assembly of the State of Indiana:

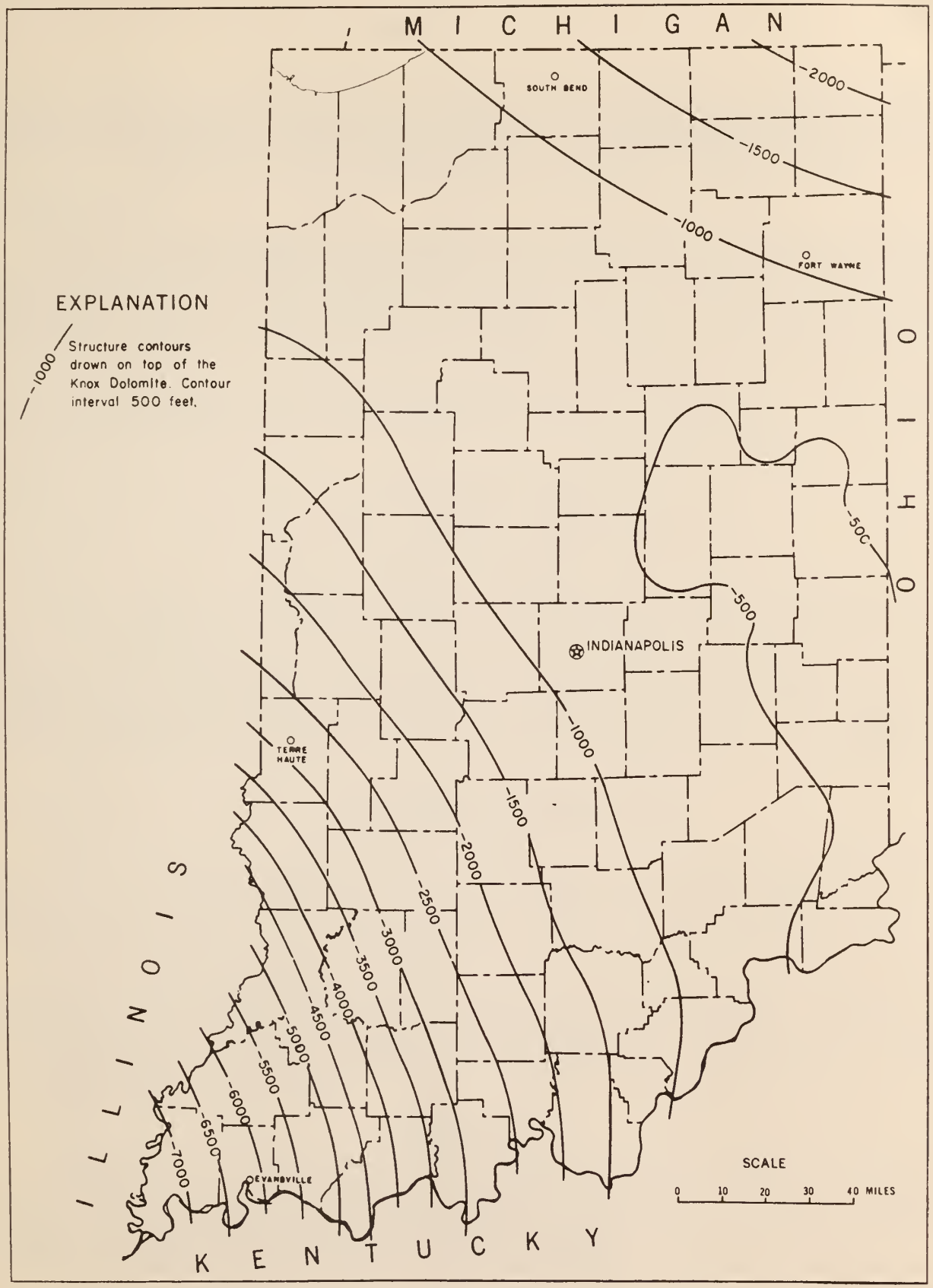


FIGURE 29. MAP OF INDIANA SHOWING REGIONAL STRUCTURE ON TOP OF KNOX DOLOMITE

"Section 1. Whereas, the storage of gas in subsurface strata or formations of the earth in Indiana tends to insure a more adequate supply of gas to domestic, commercial and industrial consumers thereof in this state and materially promotes the economy of the state, the same is hereby declared to be in public interest and for the welfare of this state and the people thereof, and to be a public use.

"Section 2. Any person, firm or corporation authorized to do business in this state and engaged in the business of transporting or distributing gas by means of pipelines into, within or through this state for ultimate public use, or any municipal corporation so engaged, may condemn subsurface strata or formations in lands, necessary rights incident thereto in lands, improvements and fixtures in or on said lands excepting buildings of any nature, and the use and occupation of subsurface strata or formations in lands, for constructing, maintaining, drilling, utilizing, and operating an underground gas storage reservoir. Without limiting the generality of the foregoing, the following rights in lands may be condemned for use in connection with the underground storage of gas, to wit: To drill and operate wells therein and thereon and to install and operate pipelines thereto and therefrom, to install and operate equipment, machinery, fixtures and communication facilities, ingress and egress to explore and examine such subsurface strata or underground formations, ingress and egress to construct, alter, repair, maintain, and operate such underground storage reservoir, the exclusive use of any subsurface strata condemned, and to remove and reinstall pipe and other equipment used in connection with any of the foregoing. Acquisition of subsurface rights in the same lands for use in connection with such underground storage. Surface rights in lands necessary for the accomplishment of the purposes herein set forth may be condemned. As a condition precedent to the exercise of the right to condemn any underground stratum or formation, or interest therein, reasonably expected to be used or useful for underground gas storage, except with respect to any proceeding under this act brought for the sole purpose of acquiring the right to explore and examine a subsurface stratum or formation in land and the right of ingress and egress for operations in connection therewith, the condemnor first shall have acquired by purchase, option, lease, or other method not involving condemnation, the right, or right of exercise of such option, if any, to store gas in at least sixty (60) percent of such stratum or formation, computed in relation to the total surface acreage overlying the entire stratum or formation deemed useful for such purpose; provided that, as to any tract under which the stratum or formation sought to be condemned is owned by two or more persons, firms or corporations, such tract shall be credited to the condemnor as acquired by it for the purpose of computing the percentage of acreage acquired by the condemnor in complying with the requirement set out herein above, if the condemnor shall have acquired from the owner or owners of the undivided three-fourths part or interest, or more, of such underground stratum or formation, by purchase, option, lease or other method not involving condemnation, the right, or right upon the exercise of such option, if any, to store gas therein. It shall not be necessary for the condemnor to have acquired any interest in the property in which the condemnee has an interest prior to instituting a proceeding hereunder.

"Section 3. The rights acquired by condemnation shall be without prejudice to the rights of the owners of such lands and interest therein to execute oil and gas leases, and for them or their lessees to drill or bore to any other strata or formation not so condemned, and to produce oil and gas discovered; provided, however, that any drilling so done, and all operations in connection therewith, shall be performed in such manner as shall protect the strata or formations so condemned against the loss of gas therefrom and against contamination of the reservoir by water, oil or other substance which will affect the use thereof for gas storage purposes. If the owners of mineral rights in lands or their lessees determine so to drill into lands in which gas storage rights have been condemned under this act, they shall give notice thereof to the owner or owners of such gas storage stratum, formation or horizon at least thirty (30) days prior to commencing such operations, which notice shall specify the location and nature of such operations, including the depth to be drilled. It thereupon shall be the duty of the owner or owners of such gas storage stratum or formation to designate all necessary procedures for protecting the gas storage area. The actual costs incurred in such operations by reason of such requirements, over and above customary and usual drilling and other costs which would have been incurred without compliance with such requirements, shall be borne by the owner or owners of such gas storage stratum or formation. No owner or lessee of any mineral interests other than gas storage rights shall be responsible for any act, or the consequences thereof, done pursuant to any such requirements. Any notice required hereunder shall be given by United States registered mail, return receipt requested, addressed to the owner or owners of such gas storage stratum condemned under this act, at the usual business office thereof.

"Section 4. Only such rights in lands necessary for use in connection with underground storage of gas and those subsurface strata adaptable for the same may be appropriated and condemned hereunder.

Rights in the subsurface of any of the lands constituting a part of a geological structure shall be deemed necessary to the operation of an underground storage reservoir in such structure. In determining the compensation to be paid to the owner of any oil producing stratum, or interest therein, condemned hereunder, proof may be made of, and consideration shall be given to potential recovery, if any, of oil from such stratum by secondary or other subsequent recovery processes, in addition to potential recovery by a primary process.

"Section 5. The appropriation and condemnation of subsurface strata or formations in lands, rights in lands incident thereto, and easements in lands and subsurface strata or formations herein authorized shall be made under and pursuant to the terms and conditions of and in the manner prescribed by an act of the General Assembly of the state of Indiana entitled 'An Act concerning proceedings in the exercise of eminent domain,' approved February 27, 1905, being Chapter 48 of the Acts of 1905, and all acts amendatory thereof.

"Section 6. Whereas, an emergency exists for the immediate taking effect of this act, the same shall be in full force and effect from and after its passage."

IOWA

H. Garland Hershey
Director and State Geologist

General Remarks

Iowa never has had commercial gas production, and the underground storage of imported gas is a relatively recent development with one structure now in use and other potential sites under active investigation. The present storage operations, as well as any planned for the future, must utilize fresh-water aquifers in areas where favorable structures exist. The accompanying map (figure 30) shows the present location of natural gas pipelines and gives an idea of the future potential if more transmission capacity is constructed or more storage facilities are developed. Any increase in underground storage operation will certainly tend to give a great many more communities in this general area the benefits of natural gas service.

Stratigraphy and Structural Geology of Iowa in Reference to Gas Storage

The generalized geologic column (figure 31) shows the major features of the stratigraphic sequence of the rocks and indicates potential gas storage zones as well as aquicludes that may be used as roofs. At least in part the hydrologic parameters of a fresh-water aquifer impose the limiting conditions on the aquifer's use as a storage zone; i. e., the transmissibility for ground water determines the velocity of gas movement and the amount of water readily released from storage determines the space available for gas.

The accompanying structure map (figure 32) is of necessity very generalized. The lack of detail is a direct result of the thick drift cover which forces geologists to depend very largely on water well samples and logs for subsurface information. However, for some areas there is enough data to infer favorable structural conditions for gas storage. These data can be studied at the Iowa Geological Survey, Iowa City. All the major aquifers are at a favorable depth in one area or another, because all the consolidated formations plunge to the southwest.

Gas Storage in Iowa

The only existing underground gas storage facility in Iowa is that of the Northern Natural Gas Company located 5 miles north of Redfield, Dallas County, Iowa. Preliminary exploration was started in 1952, followed by deep penetration the next year with injection tests beginning in 1954. The company has permits to pump 100 MMcf/day into their system for 120 days during this heating year from a present storage of 67 MMMcf. The field has an estimated total potential of 150 MMMcf.

The structure is a dome-like upheaval of approximately 180 feet in the Thurman-Redfield structural zone which affected all of the Paleozoics and was later covered by more than 100 feet of glacial drift. Gas is being placed in the St. Peter (Ordovician) and Mt. Simon (Cambrian) sandstones with the overlying shales and shaly dolomites acting as roofs. The St. Peter here is 35 to 40 feet thick at a depth of about 1,750 feet

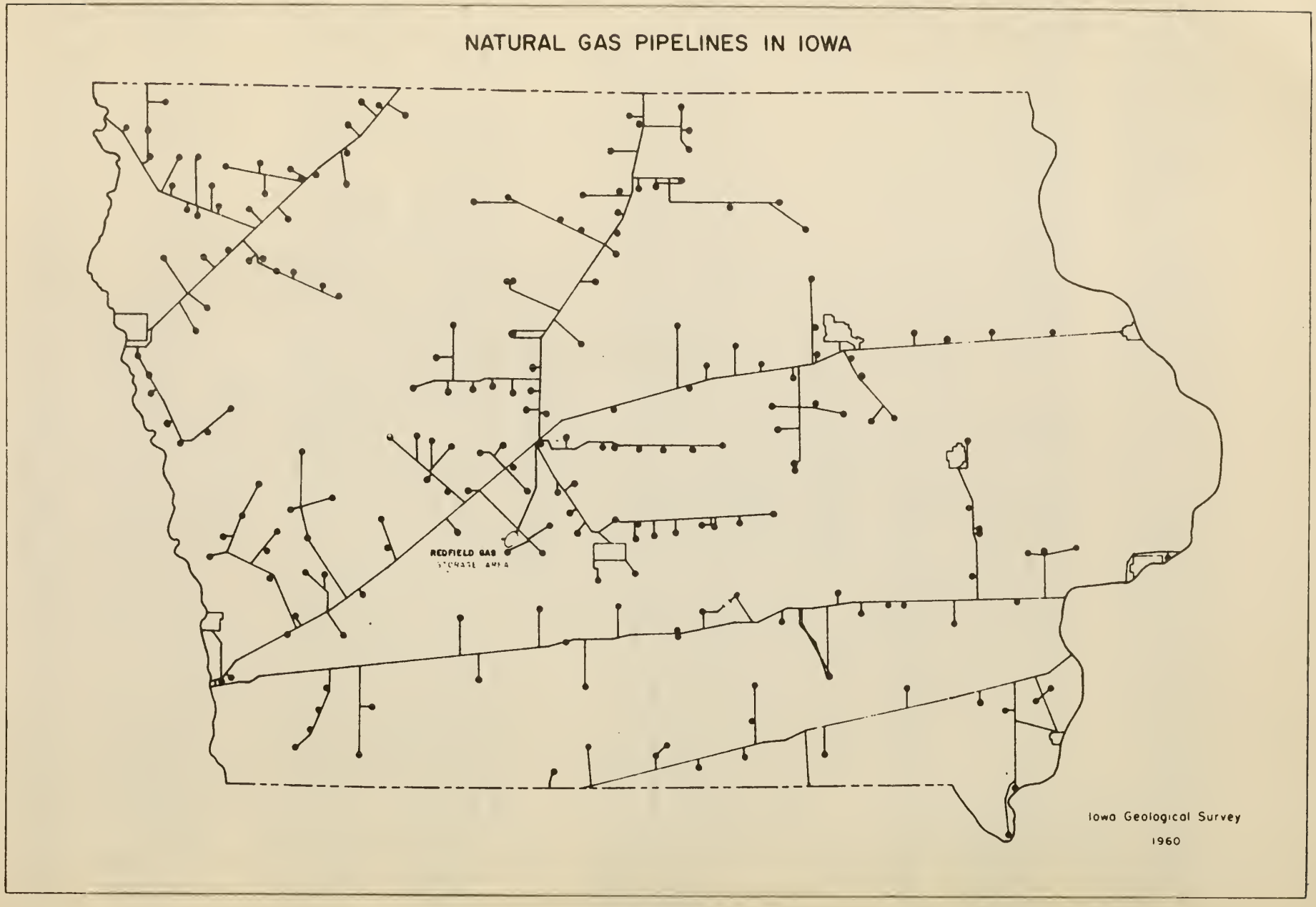

NATURAL GAS PIPELINES IN IOWA
REDFIELD GAS
Iowa Geological Survey
1960

Figure 30

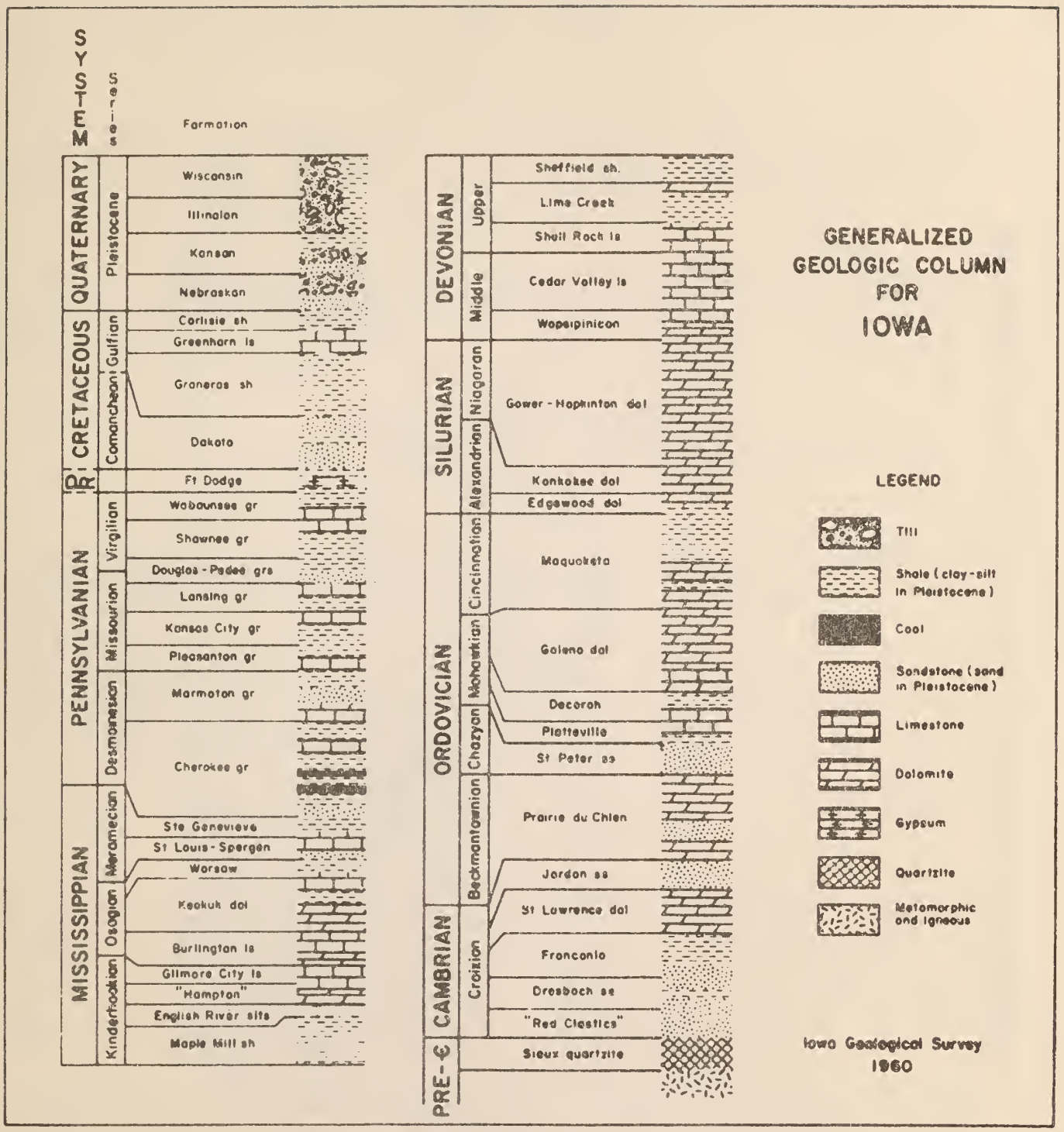
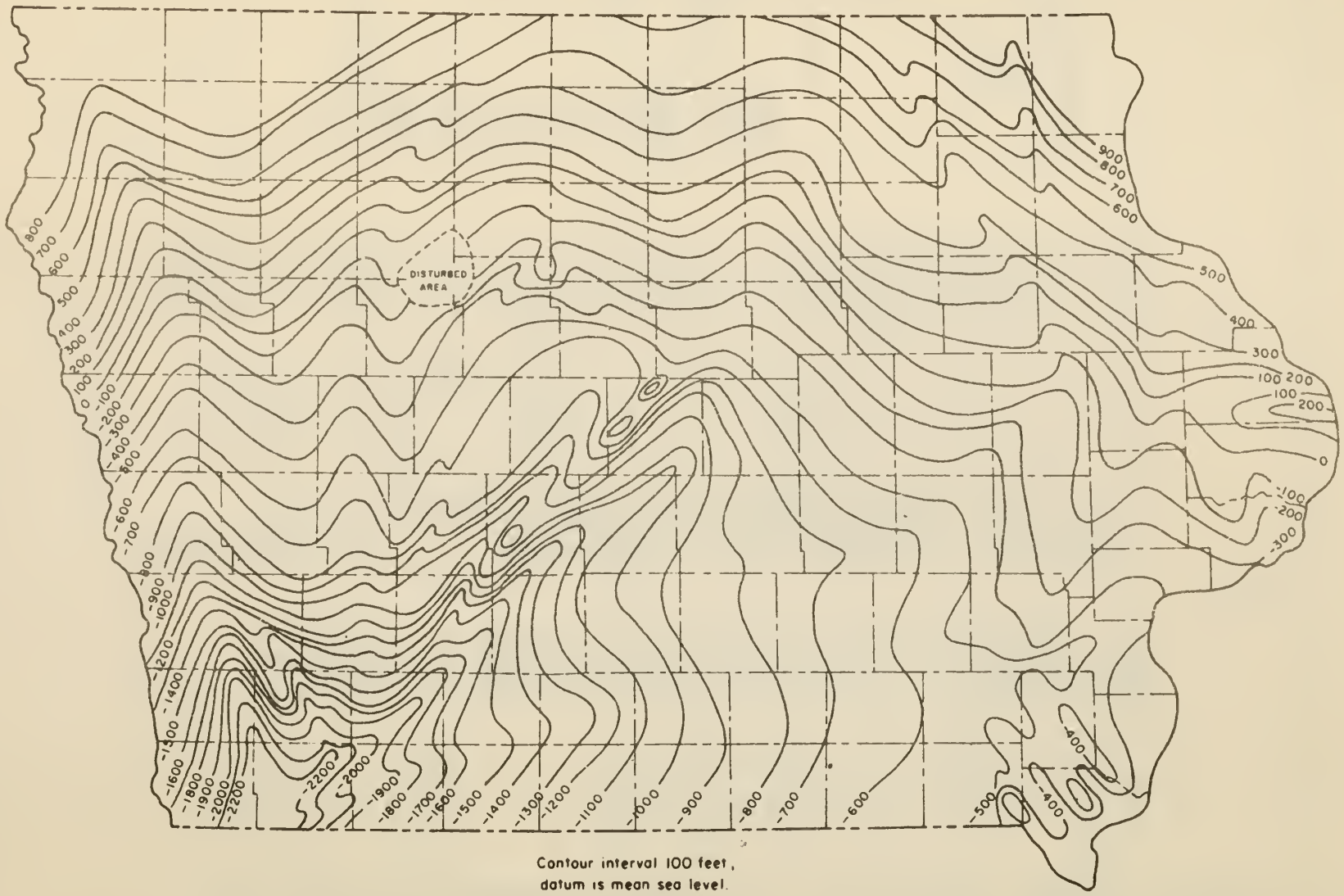

Formation
QUATERNARY
Pleistocene
Wisconsin
Illinoian
Kansan
Nebraskan
CRETACEOUS
Gulfian
Cretaceous
Carlisle sh
Greenhorn ls
Graneros sh
Dakota
Ft Dodge
PENNSYLVANIAN
Virgilian
Missourian
Desmoinesian
Wabaunsee gr
Shawnee gr
Douglas - Pedee grs
Lansing gr
Kansas City gr
Pleasanton gr
Marmaton gr
Cherokee gr
MISSISSIPPIAN
Meramecian
Osagian
Kinderhookian
Ste Genevieve
St Louis - Spergen
Warsaw
Keokuk dol
Burlington ls
Gilmore City ls
"Hampton"
English River sits
Maple Mill sh
DEVONIAN
Upper
Middle
Sheffield sh.
Lime Creek
Shell Rock ls
Cedar Valley ls
Wapsipinicon
SILURIAN
Niagaran
Alexandrian
Gower - Hopkinton dol
Kankakee dol
Edgewood dol
ORDOVICIAN
Cincinnatian
Maquoketa
Mohawkian
Galena dol
Decorah
Platteville
Chazyan
St Peter ss
Prairie du Chien
Beekmantownian
Jordan ss
CAMBRIAN
Croixian
St Lawrence dol
Franconia
Dresbach ss
"Red Clastics"
PRE-Є
Sioux quartzite
GENERALIZED
GEOLOGIC COLUMN
FOR
IOWA
LEGEND
Till
Shale (clay-silt in Pleistocene)
Coal
Sandstone (sand in Pleistocene)
Limestone
Dolomite
Gypsum
Quartzite
Metamorphic and Igneous
Iowa Geological Survey
1960

Figure 31.

GENERALIZED CONFIGURATION ON TOP OF ST. PETER SANDSTONE



Contour interval 100 feet, datum is mean sea level.

Iowa Geological Survey
1960

Figure 32.

and has very poor hydrological characteristics. The Mt. Simon is approximately 100 feet thick at a depth of about 2,650 feet and has moderately good hydrological characteristics.

Regulations

The regulations covering operations of a gas storage facility are administered by the Iowa Commerce Commission in close consultation with the Iowa Natural Resources Council and the Iowa Geological Survey and, except for State statutes concerning procedures for leasing, condemnation, and safety, are patterned closely after the regulations established by the Federal Power Commission.

Conclusion

Iowa undoubtedly has many areas capable of being utilized for gas storage, and a number of structures that are believed to be adaptable for that purpose have been mapped. Such storage is needed. The greatest difficulty confronting potential operators is the lack of structural information which necessitates a great amount of exploratory drilling.

KANSAS

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Abstract

Kansas produces large amounts of natural gas, and large quantities are consumed within the state, especially in the eastern part. At present gas is stored in 14 projects. Geologic conditions in the state are such that possibilities for storage in more underground reservoirs is very promising.

General Remarks

Annually more than 500 billion cubic feet of natural gas (14.65 psia) is produced in Kansas. At present about 70 percent of the production comes from the Kansas part of the Hugoton Gas Area which extends into Oklahoma and Texas. A large part of the Hugoton gas is transported across Kansas. Very small amounts of gas, probably less than one percent of the total, come from eastern counties. The eastern area, however, contains many depleted pools, some of which are of moderate size and all of which are at shallow depths. Underground storage of gas in depleted pools has been practiced in Kansas for many years (Jewett and Abernathy, 1945, p. 147). There are now 14 projects in operation, and it is believed that the need for underground storage facilities will increase for several years.

Because of the seasonal demand for natural gas as a fuel, underground off-season storage has become a significant factor in the overall economy of gas production, transmission, and consumption. Kansas, located in the heart of the nation geographically, contains a major source of natural gas supply (Federal Power Commission map, Dec. 31, 1958). There were 494,000 residential consumers in Kansas during 1958, utilizing 64,486,000 Mcf at an average value of 60.4 cents per thousand (Minerals Year Book, v. 2, Fuels, 1958). Commercial consumers totaled 61,000 during the year. These used 40,147,000 Mcf of gas valued at 39.1 cents per thousand. Other users of natural gas in Kansas during 1958 consisted of makers of carbon black, drillers, refineries, and other industrial users. During the year they consumed 202,557,000 Mcf valued at 20.4 cents per thousand.

The marketed production of gas in Kansas in 1958 amounted to 561,816,000 Mcf and was valued at 11.4 cents (average) per thousand cubic feet at the wellhead. Interstate movement of gas accounted for 424,547,000 Mcf. Quantity received was 237,707,000 Mcf, mostly from west-south-central United States including Arkansas, Louisiana, Oklahoma, and Texas. Consumption within Kansas amounted to only 362,280,000 Mcf or 64 percent of the marketed production.

Development cost of gas storage projects by private industry is difficult to determine and not necessarily useable because comparison between companies utilizing dissimilar storage reservoirs would be futile. During 1959, however, Cities Service Gas Company applied for permission from the Federal Power Commission, which has jurisdiction over interstate movement and sale of fuels, to construct several storage projects along its lines. The large Denton Storage Area in Elk County was listed at a cost estimated

at $4,337,000.00. The Ferguson and Denton fields will be operated as a single unit. About 200 old wells and 35 new wells will be utilized. Finished, the total storage capacity will be about 16 billion cubic feet, making it the largest in Kansas.

It is obvious that a large portion of the interstate marketed gas from Kansas is dependent on the consuming area of north-central United States for an outlet. Industrial users assume some of the seasonal slack of residential users, but even so, the need to flatten out the annual curve of consumption and market to utilize the pipeline capacity the year around, and to stabilize the gas producing industry in Kansas makes off-season storage of gas in underground reservoirs near transmission lines and en route to market both desirable and necessary.

Gas Production in Kansas

Gas was discovered in Kansas about 1860, in the Forest City Basin. In 1870, gas was discovered in the Cherokee Basin and in 1888 on the Central Kansas Uplift. By 1910, numerous industries had been established on the basis of cheap natural gas available in eastern Kansas counties. This is signified in the 1908 production, which exceeded 80 billion cubic feet of gas. Later, insufficiency of new supplies of natural gas forced out of business those pipelines dependent upon declining reserves.

Kansas now ranks fifth among gas producing states and fourth in reserves. A significant portion of Kansas annual gas production is being exported, but estimates of amounts of natural gas used for industry in the state have risen within the last few years. During 1958 natural gas was produced from 49 counties in Kansas. At the end of 1958, there were 30 gas fields in Kansas under state jurisdiction, and monthly proration schedules were issued for 22 fields. Unprorated gas fields in Kansas are limited by statute not to run in excess of 25 percent of the open-flow capacity.

Cumulative natural gas production in Kansas surpassed the 8,000,000,000 Mcf mark in 1959. This volume is more than double the total production of natural gas in Kansas prior to 1949 and four times the amount produced previous to 1938. Since 1956, annual gas production has exceeded one-half trillion cubic feet and since 1943 has been greater than one hundred billion cubic feet annually. In 1958 production was 595.2 billion cubic feet, an all-time high for the state. By far the greatest amount of Kansas gas production has come from the prolific Hugoton Gas Area in western Kansas and adjoining areas of the Texas-Oklahoma Panhandles. In recent years gas production from outside and stratigraphically beneath the Hugoton has been gaining in importance. Pennsylvanian beds principally in eastern Kansas have supplied the second largest amount of gas, about 32 percent of the total. Lesser amounts have been obtained from rocks of Mississippian, Ordovician, and Cambrian in age.

The Hugoton Gas Area proper was opened in 1922 by a well in Section 3, Township 35 South, Range 34 West, Seward County. A rapid development of the huge gas reservoir in southwestern Kansas came in the early 1940's. By the end of 1949, the number of producing wells in the field passed the 2,000 mark and the area encompassed 2,000,000 acres. At the end of 1958 there were more than 3,800 producing wells in the Kansas part of the Hugoton Gas Area.

The Hugoton Gas Area alone accounted for about 69 percent of the total Kansas yield of gas in 1957, 73 percent in 1956, 85 percent in 1955 and 1954, 92 percent in 1953, 90 percent in 1952 and 1951, 83 percent in 1950. This shows a recent rise in importance of gas production within Kansas outside the limits of the Hugoton Gas Field.

The locations of active gas fields and of major gas pipelines are shown on figure 33. The names and locations of gas storage projects and abandoned gas fields are indicated on figure 34.

Stratigraphic and Structural Geology of Kansas in Reference to Gas Storage

Figure 35 shows distribution of outcrop areas of rocks of various geologic systems in Kansas. Outcropping and other rocks above the crystalline basement complex (Precambrian) and data more or less pertinent to gas storage are listed in table 14. It is deemed that interest in gas storage at the present time primarily concerns porous rocks that are in structural positions that cause them to be actual or potential reservoirs. These are the conditions that obtain in the presently operating gas storage projects that are described in another part of this report. In Kansas almost all rocks above the Precambrian floor are sedimentary; many of the layers are relatively porous and permeable. All these rock units are in

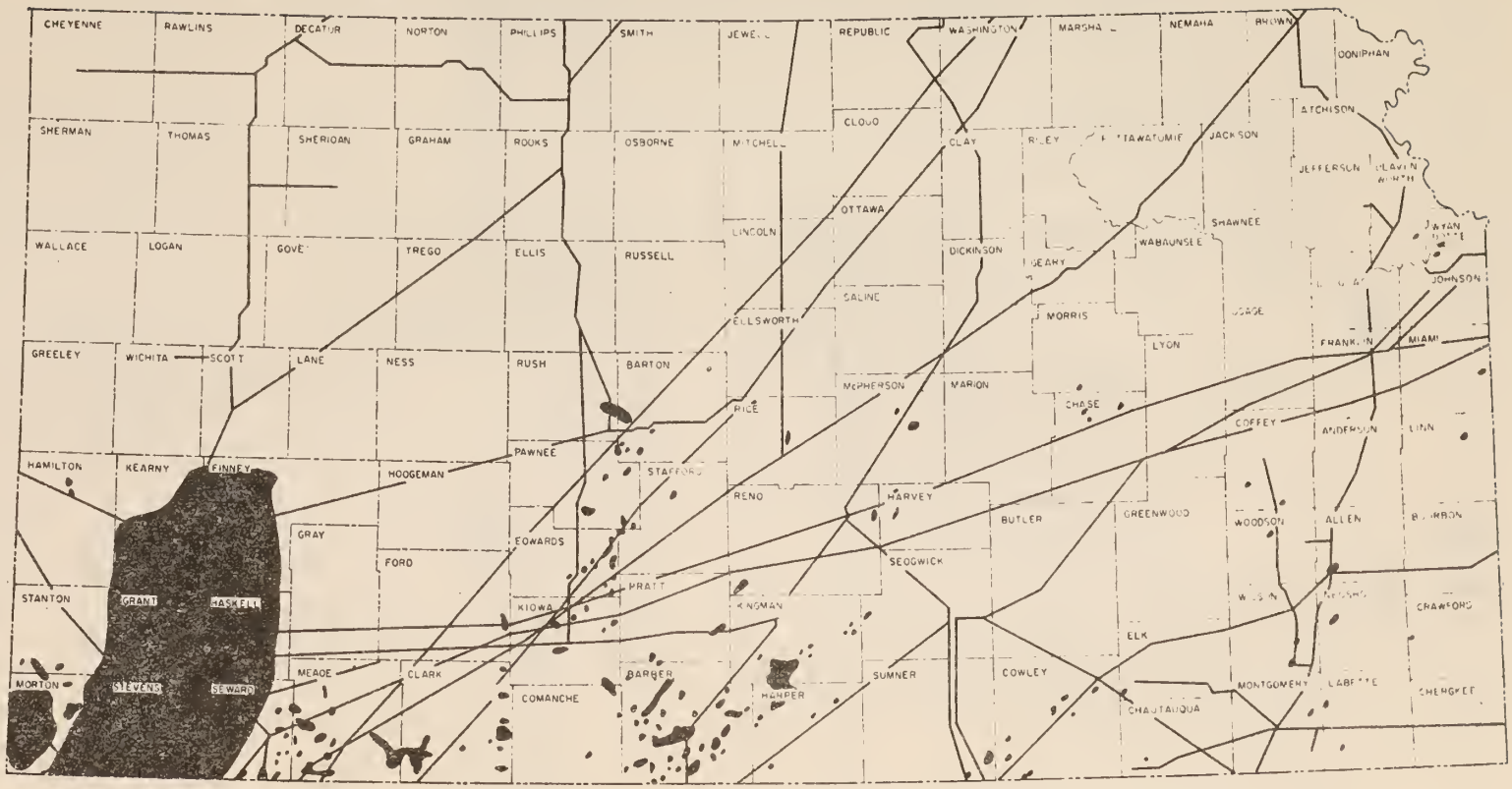

Figure 33 —Map of Kansas showing location of active gas fields and main gas transmission lines.

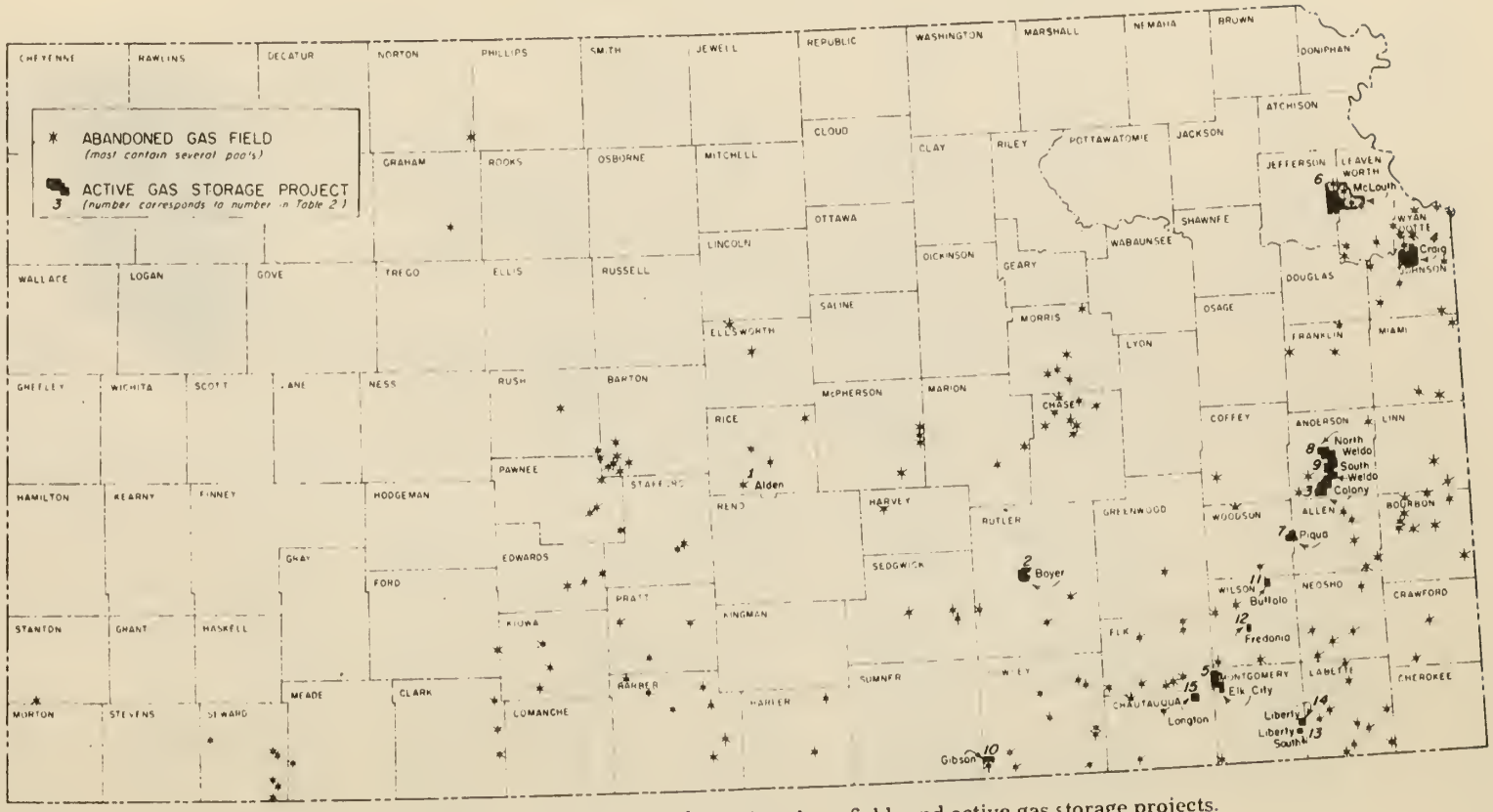

Figure 34. –Map of Kansas showing location of abandoned gas fields and active gas storage projects.

positions that are close to horizontal. Only on the flanks of major uplifts and very locally elsewhere are dips measured in angles of more than a fraction of a degree. Because of the general scarcity of faulting and steep folding, anticlinal and domal structures are relatively simple and easily defined (Jewett, 1951, 1958, 1960).

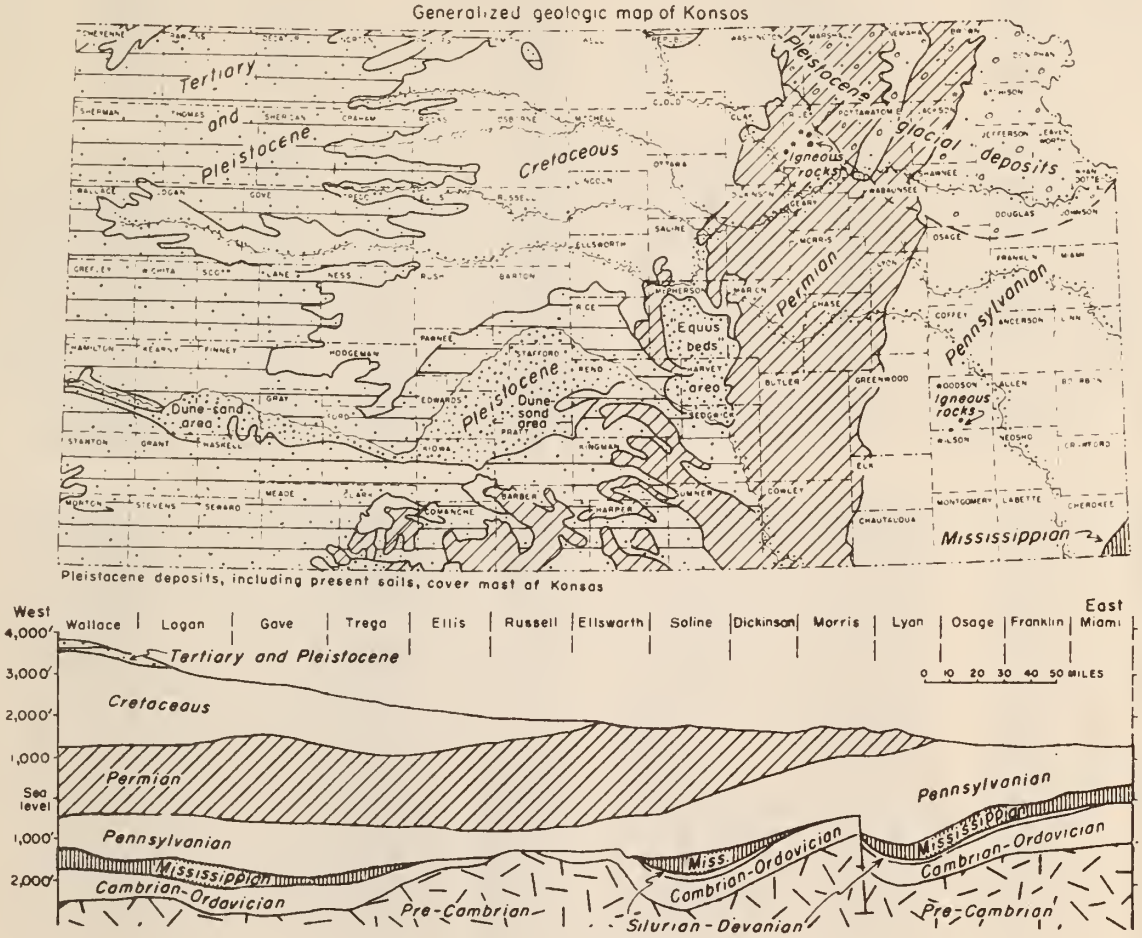

Figure 35. Generalized cross section of Kansas rocks
Generalized areal geologic map and cross section of Kansas.

Kansas Stratigraphy

Discussions of Kansas stratigraphy are found in many publications, especially of the Kansas Geological Survey. Attention is called to Bulletin 89, "The Kansas Rock Column" by Moore and others (1951), and to a chart "Graphic Representation and Classification of Rocks in Kansas" (Jewett, 1959). Here are presented characteristics of rocks of the various geologic systems (table 14 and figure 35) with special reference to porous beds. The rocks are discussed in order of increasing age, or the order in which they occur downward in the earth. As shown in figure 35, older rocks are in general at shallower depth in the eastern part of Kansas than in the western part.

For convenience, Kansas rocks may be divided arbitrarily into seven main structural categories. These divisions are defined mainly by their structural distinction each from the other. Of the seven divisions, four (Neogene, Mesozoic, Permian-Pennsylvanian, and Mississippian) are present at the surface, but the others (Devonian-Silurian, Ordovician-Cambrian, and Precambrian) are known in Kansas only from information obtained by deep drilling.

Table 14.—**Stratigraphy of Kansas in Reference to Gas Storage in Rocks**

System	Smaller stratigraphic divisions	General data	Remarks in reference to gas storage	Special references to literature
Neogene	Pleistocene or "Quaternary"	Clays, silts, sands, gravels, boulders, in surficial deposits, mostly unconsolidated, comprising soil, valley fillings, stream terraces, deposits of loess, and the glacial deposits of northeastern Kansas. Thickness as much as 300 feet.	Fresh-water bearing beds of great importance, not suited for gas storage because of shallow depth and lack of impervious sealing beds. Add to overburden. See Fig. 3 for distribution.	Moore and others, 1951, p. 13; Frye and Leonard, 1952; Geological Survey ground-water reports.
	"Tertiary" chiefly included in Ogallala Formation	Widespread in central and western Kansas, locally in eastern. Mostly stream deposits; where thin, high above present drainage. Sands, gravels, "mortar beds." Most prevalent in High Plains area. Thickness about 350 feet or less.	Fresh-water-bearing beds of importance. Shallow and generally lack impervious seals. See Fig. 3 for surface distribution.	Moore and others, 1951, p. 17; Frye, 1949; Smith, 1940; Frye, Leonard, and Swineford, 1956; Geological Survey ground-water reports.
Cretaceous	Pierra Shale, Niobrara Chalk, Carlile Shale, Greenhorn Limestone, Craneros Shale, Dakota Formation Kiowa Shale, and Cheyenne Sandstone	In outcrops and subsurface in much of central and western Kansas. Mostly marine in origin, supposed nonmarine deposits in lower part. Clayey and calcareous shales predominant, fine-grained chalky, platy limestones constituting most of the lower middle part. Plentiful sandstone in the lower part. Total thickness about 2,750 feet.	Sandstone beds, mostly in lower part, offer probable reservoirs in many areas. Surface distribution shown in Fig. 1. Not present in areas of greatest gas consumption.	Moore and others, 1951, p. 17; Plummer and Romary, 1942; Latta, 1946.
Jurassic	Morrison Formation	Subsurface in southwestern Kansas. Chiefly shale, mostly green, some gypsum and pink jasper-like chert. Thickness as much as 275 feet.	Probably lacks sufficient porosity.	Landes and Keroher, 1938.
Triassic	Dockum (?) Group	Outcrops in small area in Morton County are believed to be of Triassic age and to be properly classed as part of Dockum Group. These rocks identified in subsurface in Morton and Stanton Counties. Chiefly red siltstone and buff and white sandstone; some gypsum. Thickness about 40 feet.	Sandstone bodies probably offer structural and stratigraphic trap-like reservoirs.	McLaughlin, 1942.
Permian	Ochoan and Guadalupian Stages	Surface in southwestern and subsurface in western Kansas. Chiefly red beds of fine-grained sandstone, siltstone, and silty shale. Dolostone, gypstone, and anhydristone in middle part; much salt in subsurface. Thickness about 900 feet.	Sandstones are fine grained and of low porosity. Artificial cavaties easily made in salt.	Moore and others, 1951, p. 37; Swineford, 1955; Kulstad, 1960.
	Leonardian Stage including lower part of Nippewalla Group and the Sumner Group	Surface in southwestern Kansas and subsurface in western Kansas. Chiefly red beds of siltstone, fine-grained sandstone, and silty shale. Thick deposits of salt in the subsurface. This division has the Stone Corral (subsurface marker) Formation in the upper-middle part (and lies above more calcareous rocks of Wolfcampian age). Thickness is about 1,200 feet.	Thick salt deposits suited to development of washed-out cavities for liquid storage but probably little potential in these rocks for natural gas storage in natural traps.	Moore and others, 1951, p. 38; Swineford, 1955; Kulstad, 1960.

Table 14.—Stratigraphy of Kansas in Reference to Gas Storage in Rocks (continued)

System	Smaller stratigraphic divisions	General data	Remarks in reference to gas storage	Special references to literature
Pennsylvanian	Wolfcampian Stage containing Chase, Council Grove, and Admire Groups	Outcrops in east-central Kansas, subsurface west of outcrop belt. Chiefly marine shales and limestones. Thicker shales commonly varigated colors. Limestones massive to thin bedded. Shales mostly lack carbonaceous materials. Lower part contains some sandstone. Thickness about 500 feet.	Sandstones in lower part (and some not differentiated from sandstones in underlying Wabaunsee Group) bear gas and are suitable reservoirs for storage in anticlinal structures as along Nemaha Anticline. Great Hugoton gas pool is in deeply buried stratigraphic trap in southwestern Kansas.	Moore and others, 1951, p. 41; Moore and others, 1951a; O'Connor and others, 1953; Lee, 1949; Jewett, 1949, p. 32.
	Wabaunsee, Shawnee, Douglas, and Pedee Groups	Principally shales, limestones, and sandstones; a few thin coal beds. Sandstones lenticular or elongated. Thickest formations chiefly shale as much as 200 feet thick. Solid limestone sections generally less than 50 feet thick. Sandstones generally silty, carboniferous, and clayey, as much as 50 feet thick. Many oil and gas traps. Maximum thickness about 750 feet.	Sandstones throughout section, but more extensive in lower part, offer many reservoirs in an area extending many miles west of outcrops.	Moore and others, 1951, p. 53; Jewett, 1949, p. 32; Jewett and Abernathy, 1945, p. 29.
	Lansing, Kansas City, Pleasanton, Marmaton, and Cherokee Groups	More or less similar to units next above. Many oil and gas traps, especially in Lansing and Kansas City limestones and sandstones and in sandstones in Cherokee Group. Thickness about 1,250 feet. Outcrop belt in eastern Kansas, Kansas City area to Oklahoma line, subsurface in all Kansas west of outcrop area.	Potential storage reservoirs in many parts of section. Sandstones in lower part are suited as reservoirs in many small anticlinal structures in eastern Kansas. Important in Kansas City area.	Moore and others, 1951, p. 78; Jewett and Abernathy, 1945, p. 31; Jewett, 1949; 1954; Lee and others, 1946.
	Atokan (Bendian) and Morrowan Stages	Oilbearing rocks of lower-Middle and of Lower Pennsylvanian age in deep subsurface in southwestern Kansas. Total thickness may be 1,000 feet. ("Basal conglomerate" of various ages within the Pennsylvanian System contains oil pools in several places.)	Storage possibilities probably of little interest because of depth greater than necessary and greater than that of other suitable rocks in same areas.	Moore and others, 1951, p. 102.
Mississippian	Chesteran, Meramecian, Osagian, and Kinderhookian Stages	Chiefly massive limestones. Subsurface only, except small outcrop area in southeast corner of state. Contains lead and zinc ores in southeastern Kansas. Many oil traps, especially not far below upper eroded surface that cuts across various formations. Average thickness in eastern Kansas about 350 feet, northeastern Kansas about 500 feet, southwestern Kansas as much as 1,800 feet.	Probably of little interest at present time.	Lee, 1940; Moore and others, 1951, p. 107; Jewett, 1959.
Mississippian or Devonian	Boice Shale and Chattanooga Shale	Dark to light greenish-gray shale, silty or dolomitic, some red; also black and gray shale. Generally not more than 100 feet thick.	"Misener" sandstone locally at base of Chattanooga proposed for storage in Rice County.	Moore and others, 1951, p. 111.
Devonian and Silurian	"Hunton" Limestone	Principally dolostones, some limestones. Identified in Kansas only in central and northeastern parts. Maximum known thickness 435 feet in Nemaha County, minimum depth about 2,000 feet in Jefferson County.	Probably of little interest.	Moore and others, 1951, p. 112; Lee, Leatherock, and Botinelly, 1948; Lee and others, 1946.

Table 14.—Stratigraphy of Kansas in Reference to Gas Storage in Rocks (concluded)

System		Smaller stratigraphic divisions	General data	Remarks in reference to gas storage	Special references to literature
Ordovician		Sylvan Shale or Maquokota Shale	Greenish-gray, silty, dolomitic shale restricted principally to area of ancient Northeast Kansas Basin. Maximum known thickness about 155 feet.	Probably of little interest.	Moore and others, 1951, p. 117; Jewett, 1954a.
		Viola Limestone (Kimmswick)	Dolostone and limestone. Subsurface in most of state, but absent on principal uplifts. Thickness as much as 300+ feet.	Probably of little interest.	
		Simpson Group	Includes Platteville Formation, St. Peter Sandstone, and lower beds. Dolomitic limestones and sandstones; thickens from beveled edge to about 100 feet.	Probably of interest in the future.	Leatherock, 1945.
	Arbuckle Group	Cotter and Jefferson City Dolostones	Mainly coarsely granular, cherty dolostones. Featheredge in northern Kansas to 650 feet in Cowley County.		Moore and others, 1951, p. 116; Keroher and Kirby, 1948; Jewett, 1954, p. 55; Jewett, 1954a.
		Roubidoux Sandstone	Sandy dolomite and fine-grained sandstone. Thickness commonly 150 to 200 feet.	Important source of fresh water in southeastern Kansas.	
		Gasconade Dolostone and Van Buren Formation	Mainly cherty, coarse-grained dolostones. Gunter Sandstone in basal part of Van Buren Formation. Beveled edge to 200 feet thick or possibly more in eastern and southeastern Kansas.		
		Eminence Dolostone	Cherty, buff to white, very coarsely granular and crystalline dolostone. Beveled edge to about 150 feet in eastern Kansas, 40 to about 90 feet in west-central Kansas.		
Cambrian		Bonneterre Dolostone	Glauconitic, noncherty dolostone. Beveled edge to about 150 feet in ancient basins.		
		Lamotte Sandstone	Ill-sorted, round to angular, coarse- to fine-grained sandstone. Average thickness about 80 feet. ("Granite wash" of various ages lies on Precambrian rocks in several parts of Kansas.)		Moore and others, 1951, p. 122.
		Precambrian rocks	Igneous and metamorphic rocks of the basement complex. Underlie all of state; nearest to land surface in Nemaha County in northeastern Kansas, at greatest depth in southwestern part of state.		Jewett, 1954, p. 56; Farquhar, 1959.

Neogene rocks. - Here are included the "Quaternary" and "Tertiary" deposits that constitute a widespread more or less continuous blanket concealing the structural features in the older, consolidated bedrock. These rocks are almost entirely unconsolidated and consist of debris derived physically from older rocks; they are nonmarine in origin. They comprise alluvium in river valleys under flood plains and in terraces, and widespread sheets of loess, dune sand, and, in northeastern Kansas, glacial deposits, as well as the comparatively thick alluvium of the High Plains. The thickness of "Quaternary" deposits may range locally to 500 feet, but generally it is less than 100 feet. The "Tertiary" Ogallala Formation of western Kansas has a maximum thickness of about 400 feet. There are comparatively thin but widespread deposits of probable "Tertiary" age in eastern Kansas.

In western and central Kansas, in the northeastern glaciated part of the state, and in major and some minor stream valleys elsewhere, deposits of Neogene age are important reservoirs for fresh water; safeguards against pollution by oil and gas field wastes are important. In addition to their being impractical for gas storage because of being fresh water aquifers, the Neogene beds lack impervious seals or sufficient overburden above what otherwise might be storage reservoirs.

Mesozoic rocks. - Although there are deposits in western Kansas believed to be of Jurassic and Triassic age (table 14), most of the Mesozoic rocks of the state are Cretaceous. Strata of Cretaceous age are spread across all of northwestern Kansas and as far eastward as central Kansas (figure 35). These rocks consist of brown, ferruginous sandstones, dark clayey shales, chalky limestones, and some deposits of clay. No oil is known to occur in Mesozoic rocks in Kansas, but gas in moderate amounts has been produced near Goodland, in Sherman County, in a part of the Cretaceous section. Sandstone is characteristic of the lower part of the Mesozoic section, in the Dakota Formation, the Cheyenne Sandstone, and locally in Triassic rocks. Sandstones in the widespread Dakota Formation are lenticular within rock that chiefly is clay. Commonly the sandstone bodies, some of which are believed to be littoral and some alluvial deposits, are elongate and narrow. They are in form somewhat similar to the oil- and gas-bearing "shoestring sands" in the Cherokee Group (Pennsylvanian) in eastern Kansas. The Cheyenne Sandstone is more sheetlike than most of the sandstones in the Dakota. Porosity and permeability of these rocks are high. They are interesting as potential reservoirs for gas storage.

Sandstone-bearing Cretaceous rocks are present in the subsurface west of their outcrop belt, which is along the eastern border of the Cretaceous outcrop area (figure 35). Thickness of overburden, generally increasing westward, is about 2,000 feet in northwestern Kansas.

Permian-Pennsylvanian rocks. - As shown in table 14, the thick Permian-Pennsylvanian section in Kansas, ranging to about 6,000 feet in southwestern Kansas, comprises many kinds of rocks. The youngest and uppermost parts of this rock section, however, that are of present interest in reference to natural gas storage, are believed to be in the lower part of the Permian and in the upper part of the Pennsylvanian. Lenticular sandstones, probably filling river valleys, occur in that stratigraphic zone (Jewett, 1959). In passing it may be mentioned that thick salt deposits higher in the Permian beds are suitable for washed-out cavities. Such cavities, presently used for storing liquids, contain extensive mined-out space available for storage of gas (Jewett, 1956).

The great Hugoton Gas Pool, by definition of the Kansas Nomenclature Committee limited to the Chase Group of rocks, in southwestern Kansas (figure 33), is in a stratigraphic trap in Lower Permian (Wolfcampian) rocks. Gas accumulation there is controlled mainly by the lateral gradation of porous dolomitic marine beds updip into fine-grained dense, seemingly nonmarine strata farther west. Storage of gas in the Hugoton Area can be expected in the foreseeable future to be feasible as a gas-pressure maintenance program.

Known oil and gas reservoirs are present throughout almost the whole Pennsylvanian rock section in Kansas. Many of the hydrocarbon accumulations are in traps that are "structural" in origin, although concentrations that commonly are said to have taken place because of lateral changes in porosity, as in "shoestring sands," are plentiful.

Pervious sandstones in the upper part of the Pennsylvanian section are mentioned above because some of the uppermost ones are not clearly differentiated from some that are classed as being in the Lower Permian. Other "shoestring sand" type channel fillings and sandbars, representing local deposits of pervious materials, occur throughout most of the Pennsylvanian column, but they are most prevalent in the Douglas and Pedee Groups and especially in the Cherokee Group. Sandstones in any part of the Pennsylvanian should not be overlooked, however. In addition to sandstones, some of which are more or less sheetlike,

the Lansing and Kansas City Groups contain in central Kansas, more or less characteristically, open-textured oolitic zones that are productive in many places. Examples of oil and gas production from Lansing and Kansas City limestones are the Cunningham Field in Kingman and Pratt Counties, the Macksville Field (abandoned) in Stafford County, and the English Field in Edwards County. Oil and gas pools in Pennsylvanian sandstone are very numerous in eastern Kansas (Jewett, 1954).

As shown in another part of this report, Cherokee sandstones are most extensively used for gas storage at present. It is reasonable to expect that sandstones in the Pleasanton, Marmaton, and Cherokee Groups in the area near Kansas City will be of increasing interest as potential storage reservoirs.

Mississippian rocks. - Composed chiefly of limestone and often called the "Mississippi lime," Mississippian rocks underlie all of Kansas except on two major uplifts. They are absent in the area of the Nemaha Anticline in a belt extending from Nemaha and Marshall Counties on the northern border southward to Butler County. In the Central Kansas Uplift area there are no Mississippian rocks in a large area extending southeastward from Decatur, Norton, and Phillips Counties in the north to Pawnee, Stafford, and Reno Counties. Thickness of these rocks ranges from a featheredge on the flanks of the late Paleozoic uplifts to about 1,800 feet. The maximum thickness of Mississippian rocks in Kansas is believed to be in or near Meade County in the southwest part of the state.

A very consequential amount of natural gas has been produced from Mississippian rocks in Kansas. It is possible that partly depleted gas reservoirs may at some time be of value for gas storage. Counties that produce large amounts of gas from Mississippian rocks include Barber, Harvey, Harper, Kingman, Kiowa, and Meade. Mississippian gas pools are known in several other central and western counties.

In much of Kansas, Mississippian limestones are underlain by a rock section that is chiefly shale. This unit, generally less than 100 feet thick, probably is in part Mississippian in age and in part Devonian. Main divisions are the Boice Shale (above) and the Chattanooga Shale (table 14). In places the shale is an effective "caprock".

"Hunton" Limestone. - In Kansas, Devonian and Silurian rocks together or in places where either of the two is present, commonly are called "Hunton" Limestone. Thickness nowhere is more than a few hundred feet. These rocks have been identified in the Forest City, Salina, and Sedgwick basins. They lie unconformably below the Chattanooga (or Boice) Shale and unconformably above various older rocks. A small amount of gas has been produced from "Hunton" rocks in Kansas.

Ordovician and Cambrian rocks. - Youngest Ordovician rocks in Kansas are shale beds, some of which are silty and dolomitic, known as Sylvan, or sometimes Maquoketa Shale. These deposits now are almost confined to the area of the old Northeast Kansas Basin, an area in eastern Kansas northeast of a line from Phillips County to Cowley County and northwest of a line from Cowley County in Miami County. These deposits are of some importance as a "caprock" above Simpson and Viola oil pools; little or no gas has been found in the Sylvan in Kansas. The known thickness ranges from a featheredge to about 155 feet.

Limestone and dolostone beds that are believed to be of Middle Ordovician age and are assigned to the Viola Limestone are widespread in Kansas but are not present in the areas of major uplifts. The Viola is known to contain gas pools in a few counties, including Pratt, Reno, and Stafford. Hydrocarbon accumulations in these beds are mostly in structurally high areas in which deep weathering took place before burial under less-pervious sediments. Thickness ranges to slightly more than 300 feet.

It seems possible that sandstones in the Simpson Group of Ordovician rocks in Kansas at some time may be utilized as reservoirs for gas storage. These rocks are absent from major uplifts, but elsewhere in the state they are widespread. Simpson gas pools are known in several counties, including Barber, Comanche, Harper, Pawnee, Rice and Sumner. The thickness of the group commonly is less than 100 feet. Depths to the known gas pools range from about 3,300 feet in Rice County to about 4,860 feet in Barber County. In the Kansas City area, depth to Simpson rocks is about 1,550 feet.

The term "Arbuckle" is used in more than one way. According to accepted stratigraphic classification, the Arbuckle Group in Kansas comprises strata below the Simpson Group and above the Bonneterre Dolostone. Thus both Lower Ordovician and Upper Cambrian rocks are included (Jewett, 1959; table 14). For convenience, however, "Arbuckle" frequently is used for all Paleozoic rocks below Simpson beds and above the Lamotte Sandstone or other detrital basal accumulations on Precambrian rocks.

Arbuckle rocks are absent from the northern part of the Nemaha Anticline and adjacent areas as far west as eastern Washington County and northeastern Clay County; from higher parts of the Central Kansas Uplift in Barton, Ellis, Rush, and Russell Counties; and from the northern part of the same uplift (or the Cambridge Arch) in Decatur and Norton Counties. All divisions of the group are not distributed equally. The Cotter and Jefferson City dolostones are absent from northern Kansas. Thickness of this upper part of the Arbuckle in other parts of the state ranges to about 650 feet. The Roubidoux is believed to be the most widely distributed Ordovician formation in the state; it is probably thickest in the southeastern part. The Gasconade and Van Buren formations have been identified only in eastern and south-central Kansas. The thickness, greatest along the eastern and southern borders of the state, exceeds 200 feet. The Gunter Sandstone is the basal member of the Van Buren Formation. Locally it is 45 feet thick. The Eminence Dolostone is restricted to small areas in eastern and western Kansas. Its maximum thickness in Kansas is believed to be in eastern Kansas, where about 150 feet has been identified. Gas storage seemingly is possible but not now practicable in Arbuckle rocks.

The Bonneterre Dolostone is widespread in eastern and western Kansas but is believed to be absent from the central part of the state. Its maximum known thickness is nearly 200 feet.

Clastic deposits overlie much of the Precambrian rock surface in Kansas. Lamotte Sandstone is restricted as a name for these basal deposits by some geologists to detrital sediments that are unconformable above Precambrian rocks and conformable below Bonneterre Dolostone (Kercher and Kirby, 1948, p. 23). Others include detritus overlain by formations as high stratigraphically as the Roubidoux. "Granite wash" is a term frequently used for deposits lying on the Precambrian but overlain by sediments as young as Pennsylvanian. The thickness of these basal deposits ranges to about 100 feet but commonly is much less. Possibly at some time these beds may be of use as storage reservoirs.

It is believed that except in a few places Precambrian rocks in Kansas lack porosity sufficient for gas storage.

Structural Conditions

Middle Pennsylvanian tectonic movements segregated areas in Kansas that now conveniently serve petroliferous provinces (Moore and Jewett, 1942, figure 11). The ancient structural features that now lend their names to geographic divisions of the state (figure 36) are quite distinct from earlier and later ones (Jewett, 1958, 1960), and are almost without any indications in surface rocks. Many "structures" that are oil and gas traps within the provinces are of later development than are the large structures for which the areas are named. Also, even older structures, especially those of post-Middle Devonian - pre-Mississippian age, had given an entirely different grain to this part of the country.

Forest City and Cherokee Basins. - For present purposes, Kansas east of the Nemaha Anticline may be regarded as a unit, but it is well to note that the so-called basins are extremely broad structures and were separate areas of deposition during an extremely brief interval of time in the middle part of the Pennsylvanian period. Consolidated rocks that now are exposed at the surface in the area dip gently westward and constitute the late Paleozoic or early Mesozoic Prairie Plains Monocline (Jewett, 1951, p. 152), which properly should be recognized as extending, under cover, well into northwestern Kansas (Jewett and Merriam, 1959, figure 10). Gentle folding produced low domes, anticlines, and "noses" that are discernible in outcropping rocks. Most of the "highs" that are measurable in surface rocks are more pronounced in the subsurface, and many serve as oil and gas traps. Some "structural traps" in Pennsylvanian rocks in eastern Kansas have no or very little surface indications; some structures that are traps in pre-Pennsylvanian sediments are completely concealed. Examples of several conditions in which oil and gas occur in eastern Kansas are discussed in detail by Jewett (1954, p. 68).

Some of the gas storage projects in eastern Kansas, described in another part of this report, for example Cities Service Gas Company's McLouth project (table 15), are in structural traps of the aforementioned kind. It is believed that in almost all counties in the Forest City and Cherokee Basin area, structural conditions can be found where porous Pennsylvanian rocks would be suited for gas storage.

Much of the gas and oil that has been discovered in eastern Kansas occurs in "shoestring sands." These are elongate sandstone bodies enclosed by less pervious shale. As hydrocarbon traps these reservoirs may be uninfluenced by localized tectonic conditions and are regarded as "stratigraphic" traps. Parts of some of the elongate sandstone bodies have been arched slightly, however, probably in some

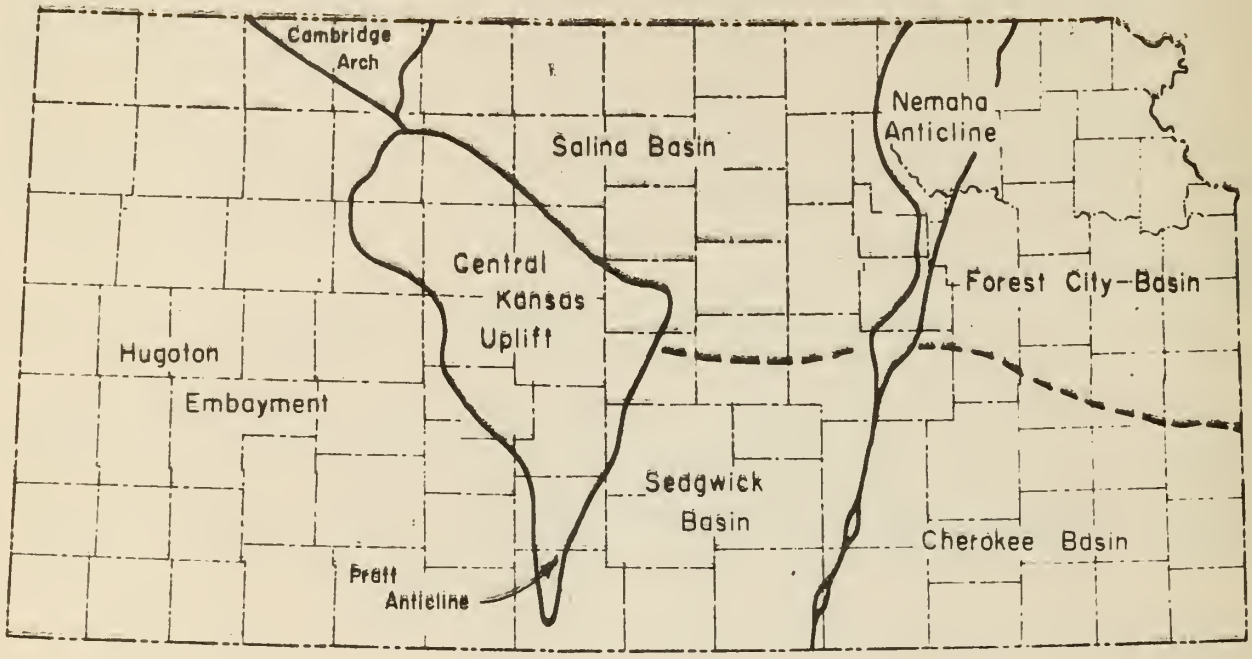

Figure 36. Map of Kansas showing location of petroliferous provinces

cases as a result of differential compaction. Cities Service's Colony Project, in Anderson County, utilizes a trap of this kind.

"Shoestring sand" oil and gas pools, at depths ranging to about 3,000 feet, except in the southwest part much shallower, averaging perhaps about 1,000 feet, are plentiful in the Cherokee Basin and the southern part of the Forest City Basin. Abandoned gas fields lie above many of them. It is reasonable to believe that gas could be stored successfully in many of these sandstone bodies, including some that have yielded gas and oil and some that have been known to contain only water. Rich (1926), Bass (1936), and Jewett (1949, 1954) have described "shoestring" oil and gas reservoirs in eastern Kansas.

In addition to the general conditions described above, some specific structures in eastern Kansas may be mentioned. They are cited here as examples of "highs" that, because of any of several factors such as cultural or other conditions within the areas, may or may not be suited for gas storage projects. They indicate deviations from the general or regional westward dip of outcropping rocks.

In the vicinity of Kansas City, the Morris Anticline is one of several folds that can be measured in surface rocks in the lower Kansas River valley. It was described by Jewett and Newell (1935) and by Jewett (1951). Other similar structures occur near Bonner Springs, De Soto, Eudora, and in several other places. Farther south in eastern Kansas there are conspicuous "highs" near Mound City, in Linn County; near Kincaid, in Anderson County; near Humboldt, in Allen County, and near Cherryvale, in Montgomery County. In Cowley and Elk Counties, in the southern part of the Cherokee Basin, several anticlines containing oil and gas pools are typical of localized structural conditions in Pennsylvanian rocks in that part of Kansas. The Elk City Field Project near Longton is in one of the Elk County structures.

Nemaha Anticline. - The well-known Nemaha Anticline, whose Precambrian core commonly is called the "Granite Ridge" and somewhat erroneously the "Nemaha Mountains," crosses Kansas from Nemaha County southwestward to Sumner County. Formed by earth movements at about the close of Early Pennsylvanian time, this buried anticline forms the west boundary of the eastern Kansas basins.

As a petroleum-bearing province in Kansas, the Nemaha is an area of slight but somewhat indefinite width. Only a comparatively small number of oil and gas traps have been found along its axis. In the southern part, the great El Dorado and Augusta oil and gas fields lie partly along the anticlinal axis. Some of the reservoirs are "structural traps" and others, commonly more prolific, are "stratigraphic traps" in beveled sub-Pennsylvanian beds. Farther south in the area, oil and gas is produced from structures more or less parallel to and near the axis and in the anticline itself. Northward from Butler County (El Dorado and Augusta fields) in the higher parts of the anticline, Pennsylvanian beds are in contact with Precambrian rocks, and only minor amounts of gas have been found in some of the Pennsylvanian sandstones. Several oil fields lie above small anticlines that are near the Nemaha structure on each of its sides. Interesting examples are found in Wabaunsee County. In Riley County, oil has been found recently in a sub-Pennsylvanian "Hunton" stratigraphic and structural oil trap on the west flank of the Nemaha structure.

Throughout much of its length the Nemaha Anticline area contains potential gas storage reservoirs. Depths range from a few hundred to 4,000 feet or more. Little research would be required to determine suitable sites for sizeable reservoirs. Known higher parts of the anticline, as near Burns in Butler County, Alta Vista in Morris County, Elmdale in Chase County, and the part north of the Kansas River are important potential storage sites.

Sedgwick and Salina Basins. - Stratigraphic and structural conditions in the two areas designated as Salina and Sedgwick Basins are sufficiently different to warrant separation as distinct petroliferous provinces. On a regional structural basis, the two parts, both lying west of the Nemaha Anticline and east of the Central Kansas Uplift (figure 36), are properly differentiated, inasmuch as there is distinct thinning of Mississippian rocks in a belt separating them. Geologic conditions in the Sedgwick Basin are more complex than in the Salina Basin.

Lenticular sandstone bodies in the lower part of the Cretaceous section in the northwestern part of the Salina Basin offer possible reservoirs for gas storage, should economic or other conditions warrant storage in this part of the state. Lack of sufficient thickness of overlying rocks might be a handicap in parts of the area.

In both basins, the gently westward dipping Pennsylvanian rocks (Jewett and Merriam, 1959, figure 10) offer numerous potential gas storage reservoirs. Investigations for porous strata in suitable structural positions would be somewhat more difficult in this general area than farther east in the state, but sufficient data seemingly are available for relatively simple studies. Depths to potential reservoirs in Pennsylvanian rocks throughout the two basinal areas range from a few hundred to about 4,500 feet.

Central Kansas Uplift. - The Central Kansas Uplift, in nearly the same area as the older (pre-Mississippian) Ellis Arch, is designated as a petroliferous province in Kansas, and is the state's most prolific oil producing area. Large amounts of gas also have been produced in the area. Oil and gas traps are somewhat complex; there are numerous examples of "stratigraphic" traps of various types below disconformities and elsewhere in the rock section. "Structural" traps are common especially in Pennsylvanian rocks.

Because of the density of drilling in the Central Kansas area, many data as to porosity and attitude of comparatively shallow rocks are available. Should gas storage in that part of Kansas become desirable, suitable geologic conditions will not be found lacking. Depths to potential reservoirs in Pennsylvanian rocks commonly are slightly in excess of 3,000 feet.

In passing, it may be noted that the northern part of the Central Kansas area is in some reports properly designated as Cambridge Arch; the extreme southern part has been called Pratt Anticline (Jewett, 1958, figure 7).

Hugoton Embayment. - All Kansas west and south of the Central Kansas Uplift area is designated as a single petroliferous province, the Hugoton Embayment. This large area was basinal both before and after the movements that produced the Central Kansas Uplift and Nemaha Anticline. The very prolific Hugoton gas producing area is in southwestern Kansas within the larger area.

"Stratigraphic" traps suitable for gas storage are believed to be plentiful, especially in post-Paleozoic rocks in western Kansas at a depth of about 5,000 feet. There are many potential "structural" traps in older and deeper rocks.

It seems probable that it may be desirable to store natural gas in the Hugoton Gas Field. The proved gas-productive part of the Hugoton area in Kansas measures about 85 miles north-south and 60 miles east-west. In the Kansas part of the field there are 3,806 producing gas wells. Gas is obtained from porous dolostones and limestones belonging to the Chase Group of early Permian age. The thickness of the productive zone is about 250 feet; within this thickness of strata there are five main gas "pays" that generally are persistent throughout the field but are not equally productive in different parts of the area. The gas-producing beds are reached at depths of about 2,560 to 2,950 feet below the surface, the average being about 2,700 feet.

The Hugoton gas reservoir is a stratigraphic trap that is due to irregular distribution of porosity along the strike (N 20° E) of the gently east dipping Permian beds. As determined from marker beds, the dip is about 15 to 20 feet per mile, and it is interrupted locally by minor deformations consisting of easterly pitching anticlines of low relief. There is no surface indication of this structure, inasmuch as the country is entirely covered by Neogene deposits that rest unconformably on Cretaceous or Permian rocks. Conditions favorable to accumulation of gas in the Permian strata are due partly to the regional structure and partly to sedimentation. Marine beds grade laterally westward updip into nonmarine strata consisting of red shale, sandstone, and arkose. The westward limits of gas-productive territory are along the zone of interfingering marine and nonmarine deposits. The chief gas-producing zones are the Fort Riley Limestone (Barneston Formation), Towanda Limestone (Doyle Shale), Winfield Limestone, and Krider and Herington limestones (Nolans Formation).

The paragraphs above outline the general structural conditions in Kansas that are of consequence to underground gas storage projects. More details may be had from numerous publications on individual fields or other areas.

Gas Storage Projects in Kansas

As of January 1, 1960, there were 14 active gas storage projects and one pending project in Kansas (table 15). The Boyer project in Butler County, Colony in Anderson County, Craig in Johnson County, Elk City in Elk and Montgomery Counties, McLouth in Jefferson and Leavenworth Counties, Piqua in Allen and Woodson Counties, and Welda North and Welda South in Anderson County are operated by Cities Service Gas Company. Consolidated Gas Utilities Corporation operates the Collinson Gas Storage Project in the Gibson Field in Cowley County. Union Gas System, Incorporated, operates five projects: the Buffalo and Fredonia in Wilson County, the Liberty North and Liberty South in Montgomery County, and Longton in Chautauqua County.

Natural gas is stored in Kansas subsurface rocks in depleted sandstone reservoirs, which are overlain and underlain by less pervious materials. Zones for storage include the Iola Limestone, "Severy," "Layton," "Squirrel," "Colony," "Bartlesville," and "Burgess" sandstones (Pennsylvanian) and the "Misener" (Devonian). In the 14 projects in the state, 661 wells are used as injection or producing wells and 68 wells are used for observation. Total storage capacity for natural gas in Kansas is 99,434,882 Mcf. Working gas makes up 36,963,657 Mcf and cushion gas 62,471,225 Mcf.

Possibilities for Additional Storage

In almost all parts of Kansas, geologic conditions are favorable for economical storage of natural gas in porous rocks. Fortunately near the centers of larger population and industries, Wichita (Sedgwick County, population 332,092), Greater Kansas City (Wyandotte County, population 184,357; Johnson County, population 141,694), and Topeka (Shawnee County, population 144,357, unofficial from 1960 census), natural reservoirs at comparatively shallow depths are believed to be sufficient for storing gas in as large quantities as may be desired in the foreseeable future.

In other parts of Kansas the porosity, permeability, and attitude of rocks are such that in almost every county gas storage projects may be initiated, it is believed, after not extensive investigation of geologic conditions. Foregoing parts of this report indicate depths and other conditions in which gas can be stored in natural geologic "traps."

Heretofore attention has been directed principally to geologic conditions that are the same as those in which gas now occurs. It is evident, however, that gas can be stored in artificial reservoirs. At the present time liquid hydrocarbons, principally liquified petroleum gas, are stored in Kansas in cavities

Table 15.—Gas Storage Projects in Kansas

Project and county	Location	Year field disc.	No. wells	No. obs. wells	Acres of formation storage	Acres controlled	Prod. depth, average	Av. net sand thickness, feet	Date first injection	Capacity, M c. f. Working gas	Cushion gas**	Total reservoir	Zone	
CITIES SERVICE GAS COMPANY														
1. Alden, Rice (Pending)		'37	12	0	711	2,695	3,320	18		5,000,000	10,857,469	15,857,469	"Misener" Devonian?	Max. pressure, 1,120 lb.
2. Boyer, Butler	Parts of sec. 5, 6, 7, 8, 9, 16, 17, 18, 20, T. 26 S., R. 5 E.	'16	14	3	1,220	2,840	880	10	6/27/29	392,279	627,588	1,019,867	Wabaunsee (formerly Shawnee) (Penn)	Max. pressure, 250 lb.; withdrawals direct from pipeline —no compressors.
3. Colony, Anderson	Parts of sec. 31, 32, 33, T. 22 S., R. 19 E; 1, 12, 13, T. 23 S., R. 19 E; 5, 6, 8, T. 23 S., R. 19 E.	'21	82	1	1,345	4,846	882	47	3/31/53	4,148,104	5,055,561	9,203,665	"Colony" (Penn)	Max. pressure 280 lb.
4. Craig, Johnson	Parts of sec. 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 33, 34, 36, T. 12 S., R. 23 E; 1, 2, 3, 4, 10, 11, 12, 14, 15, T. 13 S., R 23 E.	'23	61	24	2,360	14,967	582	23	5/31	1,557,945	4,517,875	6,075,820	"Bush City" (Penn)	Max. pressure, 205 lb.
5. Elk City, Elk and Montgomery	Parts of sec. 11, 13, 14, 23, 24, 25, 26, 35, 36, T. 31 S., R. 13 E; 19, 30, 31, T. 31 S., R. 14 E; 1, 2, T. 32 S., R. 13 E; 6, T. 32 S., R. 14 E, 15, 22, 27, 34, T. 31 S., R. 13 E; 3, T. 32 S., R. 13 E.	'18	53	6	2,057	8,319	1,354	30	4/22/58	4,500,000	15,500,000	20,000,000	"Burgess" (Penn)	Max. pressure, 630 lb.
6. McLouth, Jefferson and Leavenworth	Parts of sec. 15, 16, 17, 18, 19, 20, 21, 22, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, T. 9 S., R. 20 E; 25, 36, T. 9 S., R. 19 E; 4, 5, 6, 7, 8, 9, T. 10 S., R. 21 E; 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 17, 18, 19, 20, T. 10 S., R. 20 E.	'40	114	6	5,390	22,725	1,427	18.4	4/27/54	5,212,337	7,701,420	12,913,757	"Bartlesville" (Penn)	Max. pressure, 500 lb.
7. Piqua, Allen and Woodson	Parts of sec. 34, 35, 36, T. 34 S., R. 17 E; 1, 2, 3, 4, 9, 10, 11, T. 25 S., R. 17 E.	'22	30	8	1,090	4,390	898	20.4	8/8/55	1,551,042	1,679,430	3,230,472	"Colony" (Penn)	Max. pressure, 295 lb.; withdrawals direct from pipeline —no compressors.
8. North Welda, Anderson	Parts of sec. 16, 17, 18, 20, 21, 22, 23, 25, 26, 27, 28, 29, 34, 35, T. 21 S., R. 19 E.	'21	75	6	2,125	6,006	893	29	5/22/34	4,521,646	5,500,000	10,021,646	"Colony" (Penn)	Max. pressure, 280 lb.
9. South Welda, Anderson	Parts of sec. 2, 3, 4, 9, 10, 11, 14, 15, 16, 21, 22, 23, 26, 27, 28, T. 22 S., R. 19 E.	'21	105	6	2,528	7,595	921	32	7/12/37	5,313,617	6,475,569	11,789,186	"Colony" (Penn)	Max. pressure, 280 lb.
CONSOLIDATED GAS UTILITIES CORPORATION														
10. Gibson (Collinson), Cowley	Parts of sec. 29, T. 34 S., R. 3 E.		2	0	240		1,435	18	10/47	647,270	425,730	1,073,000	Severy Sh. (Penn)	
UNION GAS SYSTEM, INC.														
11. Buffalo, Wilson	Parts of sec. 6, 7, 8, 17, 18, T. 27 S., R. 16 E.	'16	26	1	1,708	1,708	182	15	5/42				Iola Ls. (Penn)	Injection from high-pressure transmission lines
12. Fredonia, Wilson	Parts of sec. 8, 9, 16, 17, 20, T. 29 S., R. 15 E.	'15	17	1	1,980	1,980	248	25	8/49				Kansas City "Layton" (Penn)	(Cottage Grove or Noxie) Injection from high-pressure line
13. Liberty South, Montgomery	Parts of sec. 3, 4, 5, 8, 9, T. 34 S., R. 17 E.	'14	18	3	1,565	1,565	428	35	6/48	2,524,175*	4,130,583	8,250,000	"Squirrel" (Penn)	From high-pressure line
14. Liberty North, Montgomery	Parts of sec. 21, 22, 27, 28, 32, 33, 34, T. 33 S., R. 17 E.	'14	19	2	3,002	3,002	428	35	4/54				"Squirrel" (Penn)	From high-pressure line
15. Longton, Chautauqua	Parts of sec. 2, 3, 4, 9, 10, T. 32 S., R. 12 E.	'16	33	1	3,280	3,280	659	30	3/40				"Layton" (Penn)	From high-pressure line

* Plus unused capacity 1,595,242 M c. f. as of 12/22/59
**Minimum retained for pressure maintenance.

artificially dissolved in Permian saltstone in the central and western part of the state (Jewett, 1955, 1956). There seem to be no reasons that similar "salt jugs" could not be utilized for storing gas. LPG storage projects are in operation in McPherson, Reno, Grant, and Kingman Counties. Depths below the surface range from about 400 to 1,000 feet. A more or less typical cavity is about 200 feet high and 30 feet in diameter, but some "jugs" are 40 feet high and 100 feet in diameter.

Extensive space in existing salt mines in several places in central and southern Kansas offers possibilities for gas storage. In Rice, Ellsworth, Reno, and Kingman Counties, salt has been mined by the room-and-pillar method as well as hydraulically. Room-and-pillar mining has created a great amount of possible storage space, most of which is not now utilized. It is estimated that in eight mines there is total space of almost 400 million cubic feet. Sealing off portions of these mines would be comparatively easy. The use of huge plastic bags is worthy of consideration.

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KENTUCKY

Edmund Nosow
Geological Survey

Introduction

Annual gas production for Kentucky in 1959 was 68,938,376 Mcf, of which 67,469,512 Mcf was produced in eastern Kentucky. For the ten years prior to 1959, gas production in western Kentucky amounted to less than one percent of the total gas produced in the state. Most of Kentucky's gas development has occurred in the Big Sandy Gas Field which includes parts of Martin, Johnson, Magoffin, Floyd, Pike, Knott, Perry and Letcher Counties (figure 37). During the early 1920's many scattered gas fields in western and central Kentucky produced gas for domestic and public utility needs, but most of these old fields have long since been depleted. The average production for all of western Kentucky for the last ten years has been about 500,000 Mcf in comparison to eastern Kentucky's average of over 70,000,000 Mcf.

The major part of eastern Kentucky gas production is derived from the Devonian Black Shale, although substantial yields have been recovered from other Devonian, Mississippian and Pennsylvanian reservoir beds. Improved techniques in well completion methods in recent years have done much to increase the initial production of sand and lime wells. Practically all of the Devonian shale wells are completed by shooting with 5,000-10,000 lbs. of nitroglycerine. An increased use of rotary drilling equipment, particularly air rotaries, in eastern Kentucky has characterized the modern approach to gas production in this part of the state.

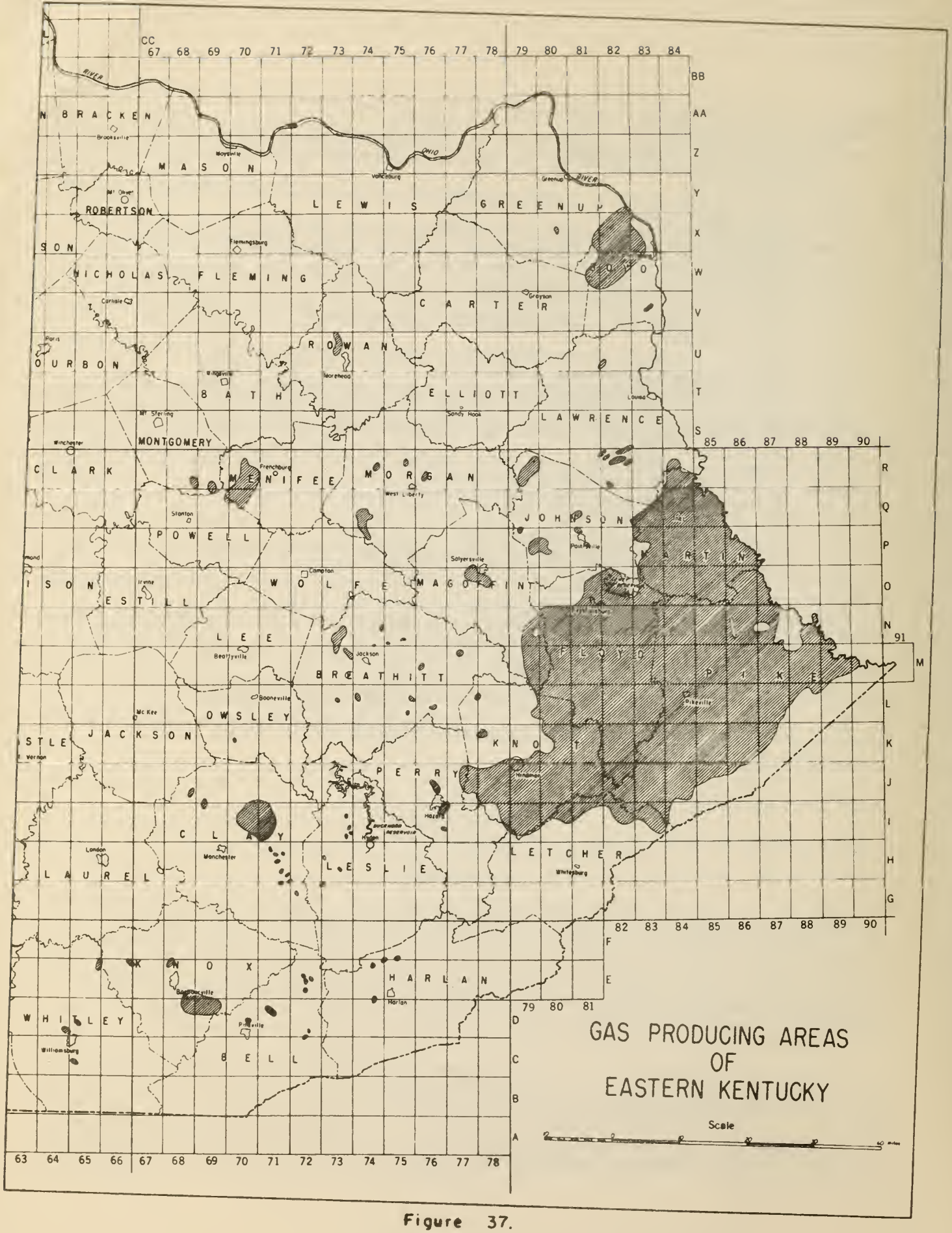

GAS PRODUCING AREAS
OF
EASTERN KENTUCKY
Scale
BRACKEN
MASON
ROBERTSON
LEWIS
GREENUP
NICHOLAS
FLEMING
CARTER
BOYD
ROWAN
BATH
ELLIOTT
LAWRENCE
MONTGOMERY
CLARK
MENIFEE
MORGAN
JOHNSON
POWELL
MARTIN
WOLFE
MAGOFFIN
ESTILL
LEE
FLOYD
PIKE
BREATHITT
OWSLEY
JACKSON
KNOTT
PERRY
CLAY
LESLIE
LETCHER
LAUREL
KNOX
HARLAN
WHITLEY
BELL
OHIO
RIVER
Brooksville
Maysville
Vanceburg
Greenup
Mt Oliver
Flemingsburg
Carlisle
Grayson
Paris
Wingsville
Morehead
Mt Sterling
Sandy Hook
Louisa
Winchester
Frenchburg
West Liberty
Stanton
Paintsville
Salyersville
Campton
Irvine
Beattyville
Jackson
Booneville
Mc Kee
Vernon
Hindman
Hazard
Hyden
London
Manchester
Whitesburg
Barbourville
Pineville
Harlan
Williamsburg

Figure 37.

The map of gas producing areas in eastern Kentucky (figure 37) shows the concentration of production in the Big Sandy Field. With the decline in production of proved areas in this field additional semi-proved areas in Letcher, Perry, Knott and Lawrence Counties have become increasingly important.

General Geological Features

A glance at the geologic map of Kentucky (figure 38) shows the major geologic subdivision of the state. Pennsylvanian strata are found on the surface in the western and eastern coal fields. These two areas are the principal regions of oil and gas production. Immediately bordering the coal fields, the Mississippian Plateau region has provided the setting for additional shallow gas and oil production. The Cincinnati Arch, a major structural feature which more or less divides the state into eastern and western halves, passes through the center of the Jessamine or Lexington Dome in the north-central region and continues southwestward through Cumberland County towards the Nashville Dome. The area of north-central Kentucky is virtually barren of oil and gas, but the flanks of the Cincinnati Arch to the south have yielded many fine shallow oil fields in Silurian and Devonian strata. The Jackson Purchase region west of the Cumberland River, which is covered by Tertiary and Cretaceous beds, is a virtually untested area for oil and gas, although possibilities in Paleozoic reservoir beds are not considered too favorable.

The Rough Creek fault zone in western Kentucky is the most important structural feature influencing oil and gas accumulation, although faulting in the Illinois-Kentucky fluorspar area traced eastward has also influenced much of the oil entrapment of the shallow rim area of this part of the Illinois Basin.

Appalachian deformation in eastern Kentucky with pronounced folding and faulting gave rise to such features as the Paint Creek Uplift, Rockcastle River Uplift, Kentucky Geosyncline and Middlesboro Basin. The Pine Mountain fault block, and Irvine-Paint Creek fault zones are examples of thrust faulting in eastern Kentucky. Despite the many major structural features found here, most of the oil and gas production is believed to be the result of stratigraphic type traps.

Gas Storage Projects in Kentucky

A large number of gas transmission lines cross the State of Kentucky, but there are still vast areas within the state which do not have natural gas facilities available for use. The large cost involved in building connecting and feeder lines to the more remote communities, and the limited market for consumption in these areas make the possibility of additional available supplies unlikely under present market conditions. The Gas Transmission Line map (figure 39) shows the major network of gas lines spanning the state.

Much of the gas consumed for home use as well as for expanding industrial developments is brought into the state by means of a system of major gas transmission lines, and is subsequently distributed by smaller feeder lines (figure 39). Several companies engaged in the sale of natural gas do not have commercial gas production within the state and must depend wholly on outside sources. Storage facilities must be utilized to keep reserve stores on hand, to be used during peak demands in the winter.

Gas storage facilities are located in all parts of the state and vary widely in size of storage reservoir, nature of storage reservoir and age of containing beds.

Four companies maintain nine separate underground gas storage facilities within the state, only one of which is in eastern Kentucky. Two additional areas in western Kentucky have been considered and will probably be utilized for storage in the near future.

The Texas Gas Transmission Company maintains three storage fields: the Dixie Field in Henderson County, and the Hickory School and Grandview Storage Fields in Daviess County. For purposes of this report the two Daviess County areas can be considered as comprising the Whitesville storage area.

The Dixie Storage Field is in a basal Pennsylvanian sand lens which originally produced small amounts of gas. Nearby oil production in the same zone is found in the West Dixie Pool. The sand lens "A" is approximately 450 feet below limestone markers, and in many cases there are two additional sand lenses designated "B" and "C", below the "A" zone. A typical electric log showing this storage zone is given in figure 40.

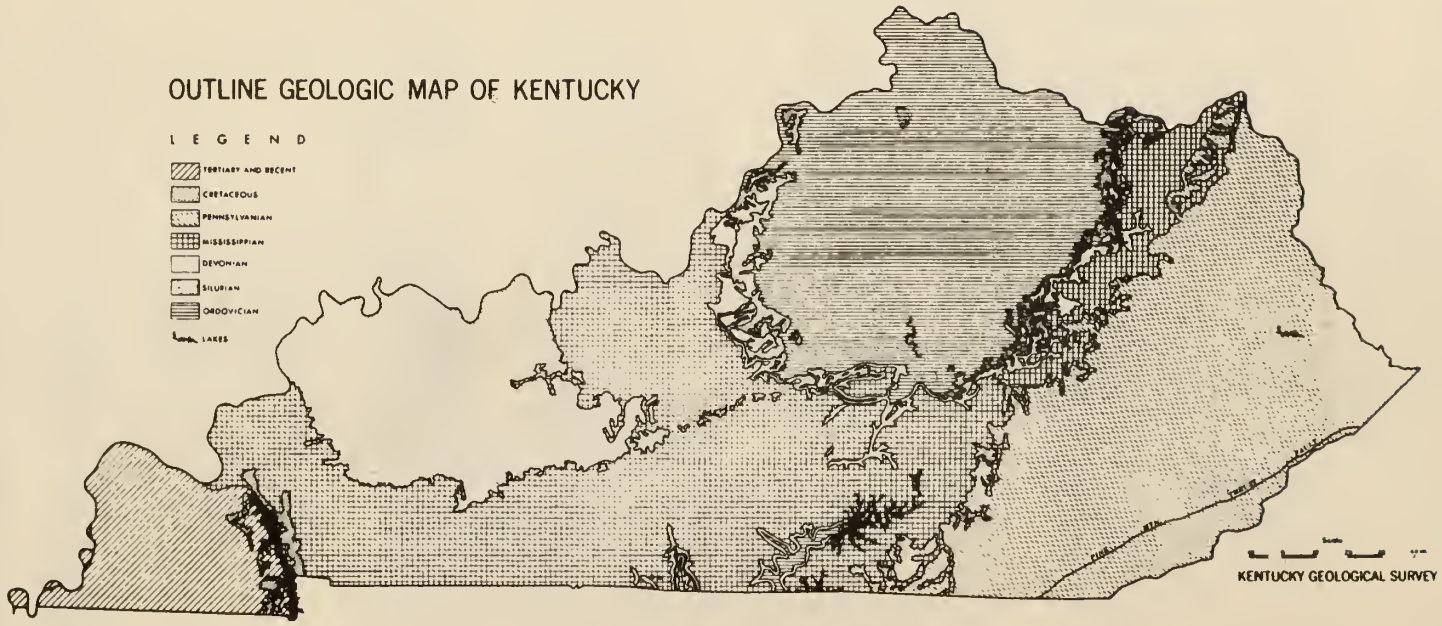

OUTLINE GEOLOGIC MAP OF KENTUCKY
LEGEND
TERTIARY AND RECENT
CRETACEOUS
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
LAKES
KENTUCKY GEOLOGICAL SURVEY

Figure 38.

GAS TRANSMISSION LINES AND UNDERGROUND GAS STORAGE FIELDS IN KENTUCKY

1 OIXIE
2 KIRKWOOD SPRINGS
3. JUOGES CHAPEL (Potential storage area)
4 LUZERNE (Potential storage area)
5 WHITESVILLE
6 OWENSBORO
7 MAGNOLIA
8 MULORAUGH
9 DOE RUN
10 MENIFEE

LEGEND

TRANSMISSION LINES
In Service
Line Under Construction or Authorized

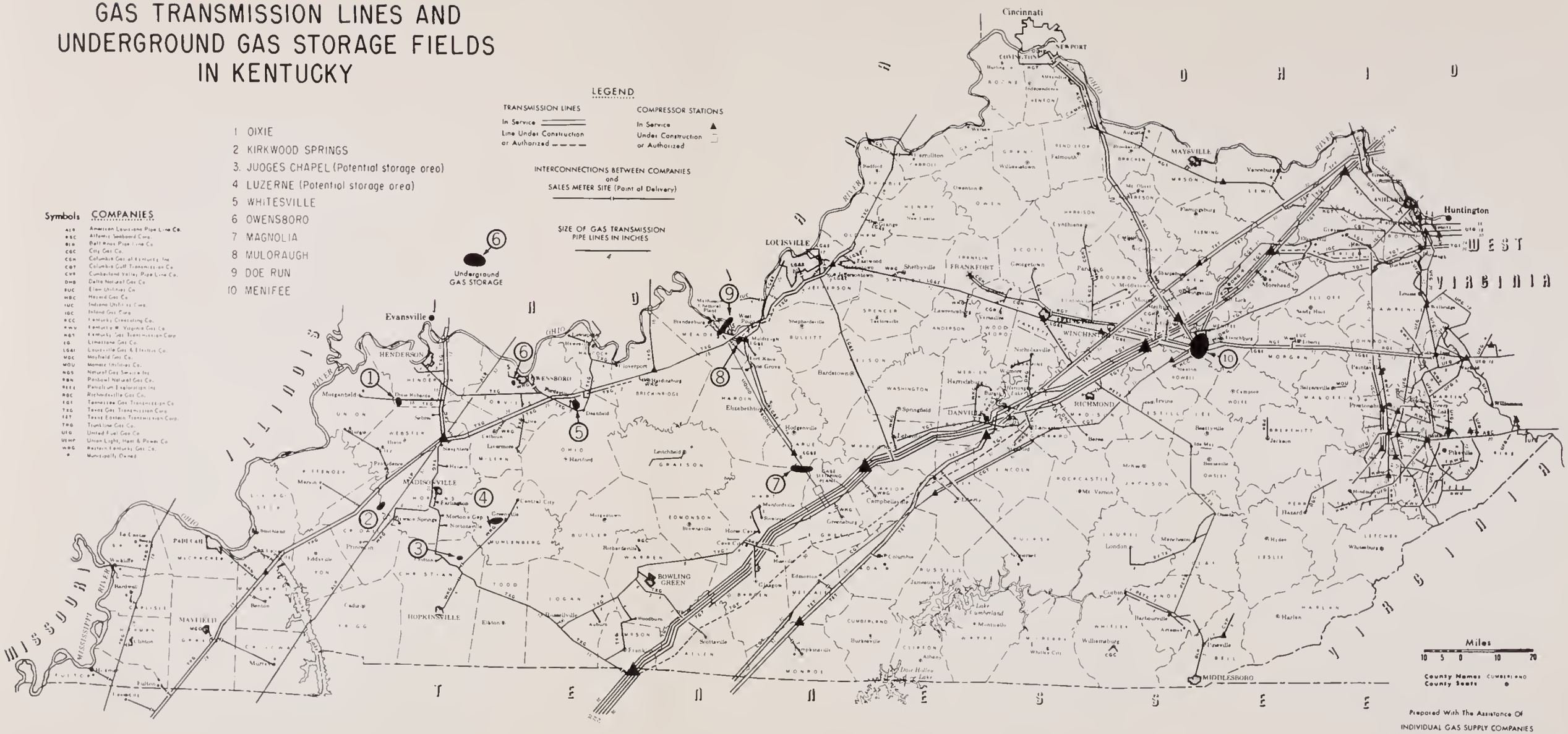
COMPRESSOR STATIONS
In Service
Under Construction or Authorized

INTERCONNECTIONS BETWEEN COMPANIES and SALES METER SITE (Point of Delivery)

SIZE OF GAS TRANSMISSION PIPE LINES IN INCHES

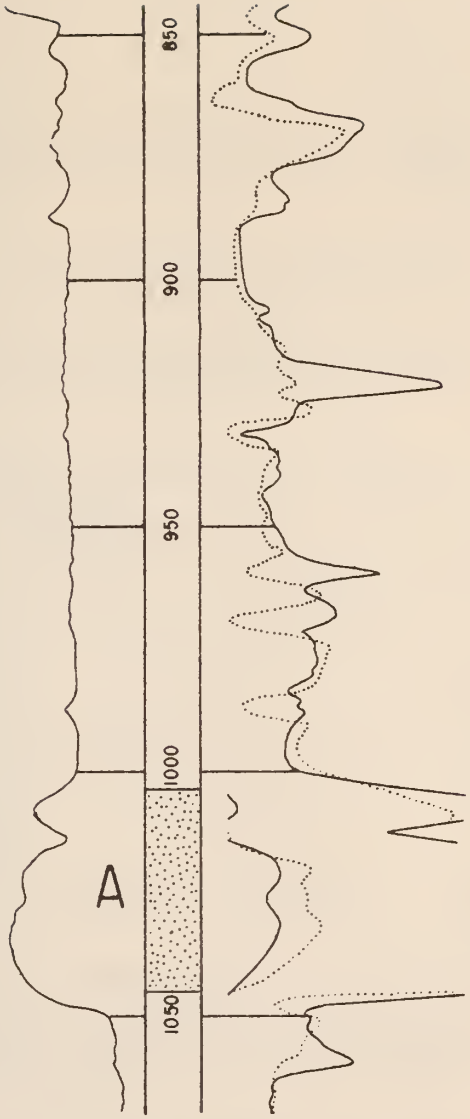
Symbols COMPANIES

AIG	American Louisiana Pipe Line Co.
ASC	Atlantic Seaboard Corp.
BLP	Bell Pipe Line Co.
CGC	City Gas Co.
CGK	Columbia Gas of Kentucky Inc.
CGT	Columbia Gulf Transmission Co.
CVP	Cumberland Valley Pipe Line Co.
DHG	Delta Natural Gas Co.
EUC	Elon Utilities Co.
HBC	Hazard Gas Co.
IUC	Indiana Utilities Corp.
IGC	Inland Gas Corp.
KCC	Kentucky Consolating Co.
KWV	Kentucky & Virginia Gas Co.
KGT	Kentucky Gas Transmission Corp.
LG	Limestone Gas Co.
LG&E	Louisville Gas & Electric Co.
MGC	Mayfield Gas Co.
MOU	Monroe Utilities Co.
NGS	Natural Gas Service Inc.
PBN	Panhandle Natural Gas Co.
PEX	Petroleum Exploration Inc.
RGC	Richardsville Gas Co.
TGI	Tennessee Gas Transmission Co.
TXG	Texas Gas Transmission Corp.
TET	Texas Eastern Transmission Corp.
TPG	Trunkline Gas Co.
UFG	United Fuel Gas Co.
UHP	Union Light, Heat & Power Co.
WKG	Western Kentucky Gas Co.
*	Municipally Owned



Prepared With The Assistance Of
INDIVIDUAL GAS SUPPLY COMPANIES
PUBLIC SERVICE COMMISSION OF KENTUCKY

Figure 39



ELECTRIC LOG SHOWING "A" SAND ZONE
OF TRADEWATER FORMATION
Dixie Storage Field, Henderson Co., Ky.

Figure 40.

The general stratigraphy of the Whitesville storage area can be observed in the stratigraphic section shown by figure 41. The Hickory School Field, a depleted gas area, occupies a zone in the Middle Paint Creek Sand which is locally called the "Bethel sand". The true Bethel Formation of this area is a shale zone and nonproductive.

The Grandview storage facility, which formerly produced gas from the Cypress Sand, Mississippian Chester, now utilizes this zone, locally called "Barlow sand," for storage.

Both the Hickory School and Grandview installations handle relatively small amounts of gas, as can be seen from the figures in table 16. A detail map of the Dixie and Whitesville areas is presented in figure 42.

Table 16 - Texas Gas Transmission Storage Fields

Name and Location	Geological Formation	Total gas Mcf	Capacity Pressure, lbs.	Active Gas, Mcf	Cushion Gas, Mcf
Dixie Storage Field Henderson County, Kentucky	Basal Pennsylvanian (Sand Lens)	7,114,500	465	2,524,500	4,590,000
Hickory School Storage Field Daviess County, Kentucky	Mississippian (Bethel Sand Lens)	1,000,000	440	409,020	590,980
Grandview Storage Field, Daviess County, Kentucky	Mississippian (Barlow Sand Lens)	612,480	435	260,480	352,000

The Western Kentucky Gas Company maintains a small storage facility west of Owensboro in the Waltersburg Sandstone. Unlike the Whitesville area where it is shaled out, the Waltersburg Sandstone is here well developed between the Vienna and Menard limestones at a depth of about 1,200 feet. Three wells for input and withdrawal are maintained, although possibilities for increasing the storage area are present.

The Kirkwood Springs area originally produced gas from the Palestine Sandstone at depths of 1,100-1,300 feet, and many of the wells originally produced open flow volumes of 1,000-10,000 Mcf. A typical electric log of the area (figure 43) shows the Palestine storage zone. The field is a depleted gas dome.

Table 17 - Western Kentucky Gas Company Storage Fields

Name	Location	No. of Wells	Maximum Capacity	Producing Formation	Average Depth ft.	Type of Reservoir
Owensboro Gas Storage Field Daviess County, Kentucky	25-P-29	(3) Injection and withdrawal	50,000 Mcf @ 562#	Waltersburg	1,200	Depleted Gas Field
Kirkwood Springs Gas Storage Field Hopkins County, Kentucky	16, 17, 24, 25-J-22	(11) Injection and withdrawal	500,000 Mcf @ 474#	Palestine	1,100	Depleted Gas Field

The additional two areas which are indicated on the Transmission and Storage map are the Judge's Chapel Gas Pool in Christian County and the Luzerne Gas Pool in Muhlenberg County. The former is an

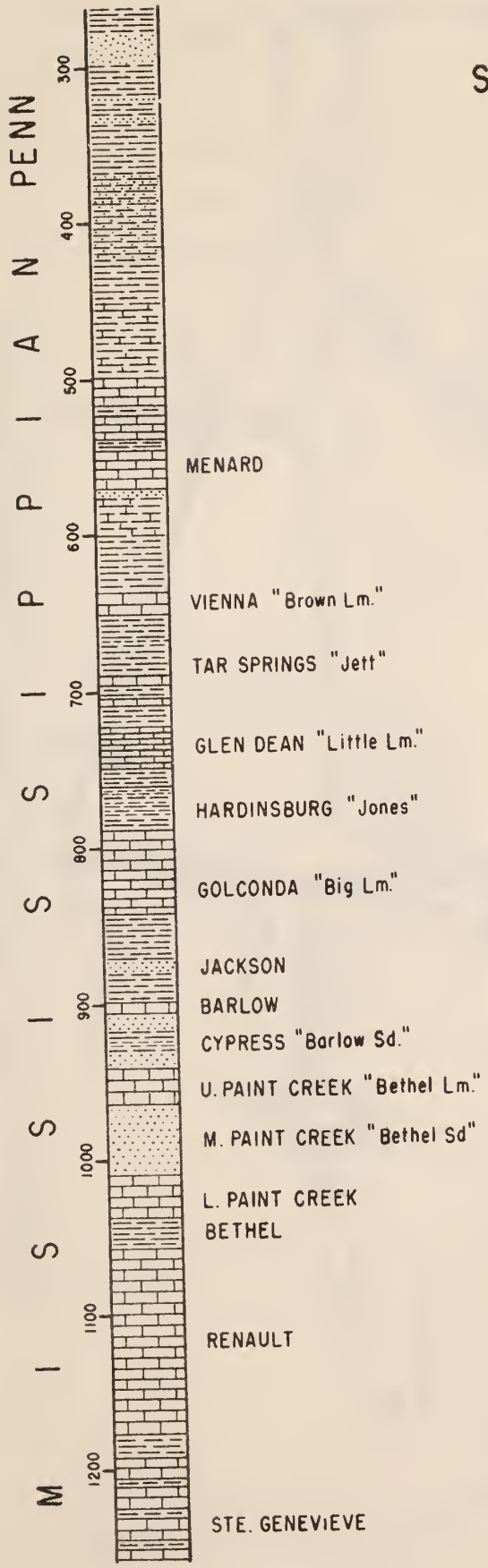
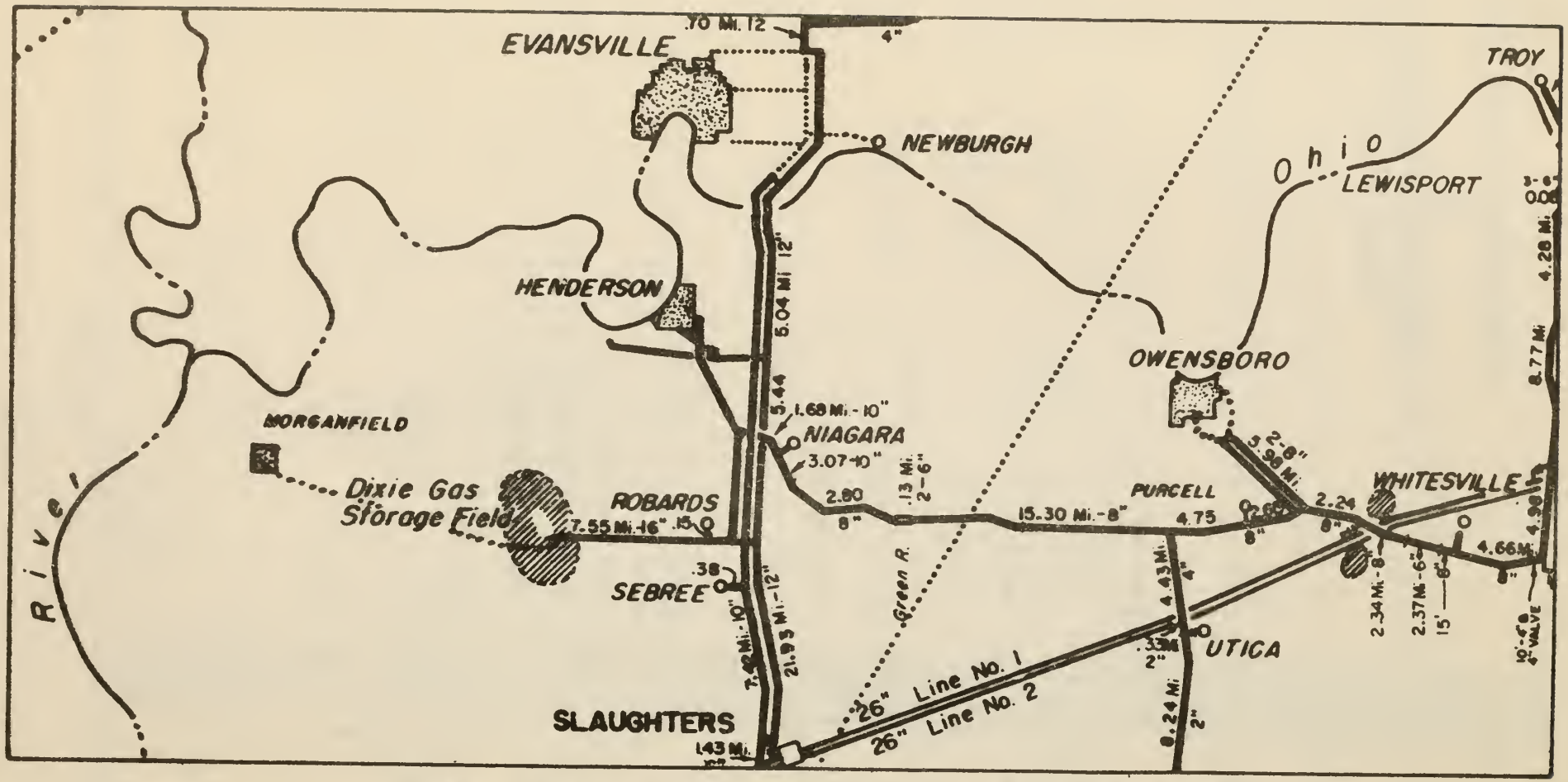

STRATIGRAPHIC SECTION
OF
WHITESVILLE AREA
Daviess Co., Ky.
PENN
MISSISSIPPIAN
300
400
500
600
700
800
900
1000
1100
1200
MENARD
VIENNA "Brown Lm."
TAR SPRINGS "Jett"
GLEN DEAN "Little Lm."
HARDINSBURG "Jones"
GOLCONDA "Big Lm."
JACKSON
BARLOW
CYPRESS "Barlow Sd."
U. PAINT CREEK "Bethel Lm."
M. PAINT CREEK "Bethel Sd"
L. PAINT CREEK
BETHEL
RENAULT
STE. GENEVIEVE

Figure 41.

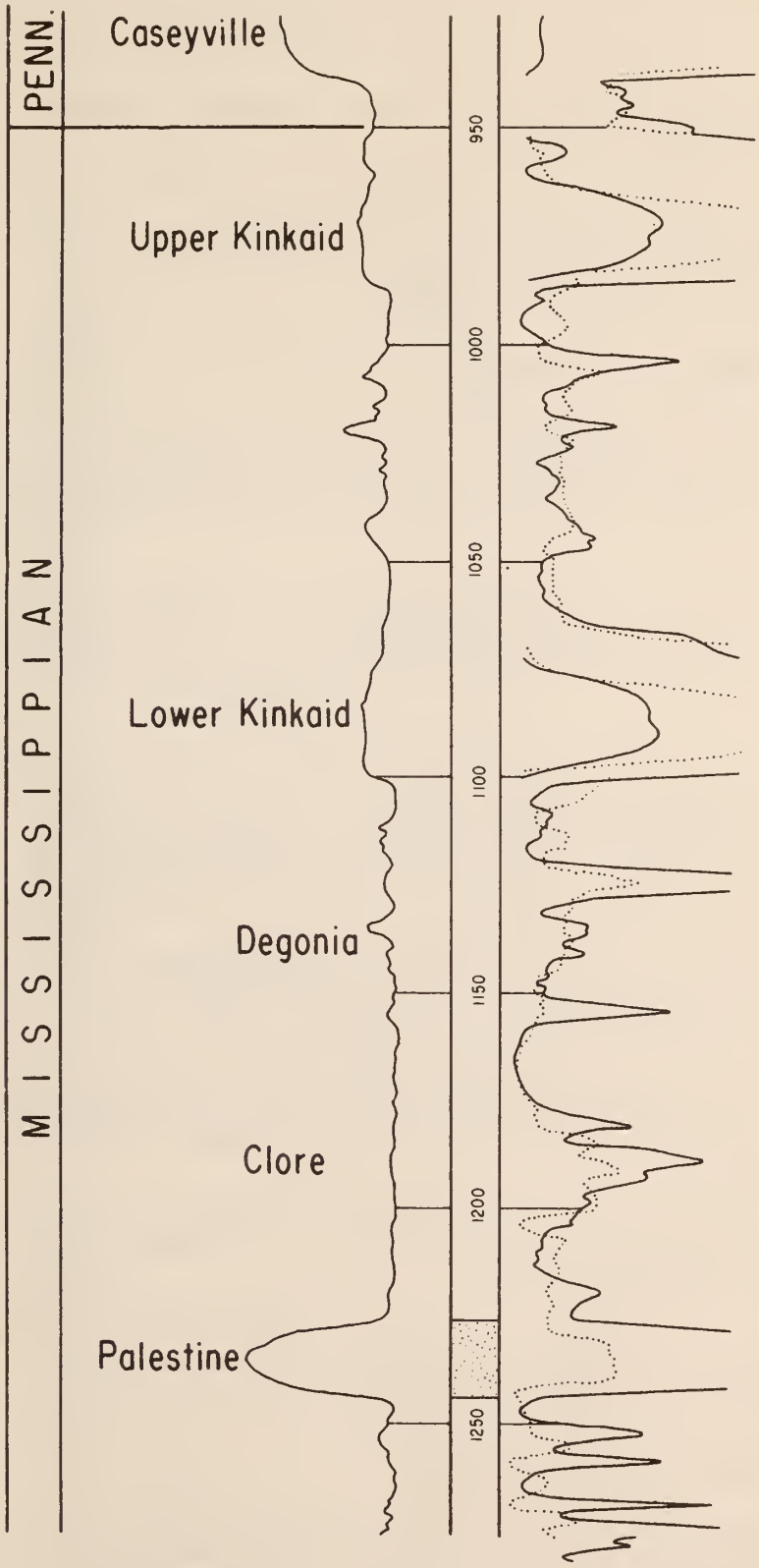


DETAIL OF DIXIE AND WHITESVILLE STORAGE AREAS

0 10 20 30

SCALE IN MILES

Figure 42.



ELECTRIC LOG OF UPPER CHESTER
Kirkwood Springs vicinity, Hopkins Co., Ky.

Figure 43.

area of Bethel Sand production which has been operated by Western Kentucky Gas Company and will likely be used for storage at some time in the near future.

The Luzerne Gas Pool is a currently productive gas area which was acquired by the Texas Gas Transmission Company recently, in part from Western Kentucky Gas Company. Many of the wells in this pool have initial open flow exceeding 5,000 Mcf per day from the Bethel Sand.

Typical stratigraphic sections of the two areas are shown in figures 44 and 45.

The Louisville Gas and Electric Company maintains three separate storage fields in west-central Kentucky.

The Doe Run Field in Meade County, Kentucky, and Harrison County, Indiana, is the only aquifer which is currently used in the state for gas storage. Gas is now being stored in the Devonian Jeffersonville and Silurian Brownsport, and tests of the Silurian Louisville are now under way for additional potential gas storage area. A stratigraphic section and structure map of the field are presented in figures 46 and 47.

The Muldraugh Storage Field is a dome with approximately 220 feet of closure. For many years it has been postulated that the structure was cryptovolcanic in origin, partly because of the thin Silurian section below the New Albany Shale and the reworked Knox Dolomite and chert below the Silurian. A stratigraphic section and structure map contoured on the base of the New Albany Shale are shown in figures 48 and 49.

The Magnolia Storage Field in Hart, Green, and Larue Counties is considered to be a westward plunging anticline. A stratigraphic pinchout of the Louisville on the northern edge of the field provides additional storage reservoir. The Silurian Louisville Limestone is utilized at present for storage, but the underlying Laurel is currently being tested. The original gas in the reservoir was a highly sulphurous sour gas, and a cleaning plant was installed to purify the stored gas which is contaminated by the native cushion gas. A stratigraphic section and structure map of the area are presented in figures 50 and 51.

The United Fuel Gas Company maintains a storage pool in Menifee County in the old Rothwell gas area. It is the only storage facility in the eastern part of the state. The discovery well in the field was drilled in 1904 and had an initial open flow of 460 Mcf at 90 psig rock pressure. Approximately 180 wells were drilled, and production was derived from a crenulated monocline in the "Corniferous". The field was used for consumer supply in Mt. Sterling, Winchester, and Lexington until 1912. When Central Kentucky Natural Gas Company extended its lines to Inez for consumer needs, the field was used only for meeting peak demands. In 1919 repressuring was started, and the field was used for small scale storage until 1948. Major storage operations were started in 1948, and a maximum volume of 12,000,000 Mcf at 130 psig was reached in November 1949.

The storage capacity of the field has been gradually reduced since 1952 for economic reasons. During 1959 the maximum storage volume was 4,850,000 Mcf at 65 psig. The maximum 24-hour delivery during the 1959-60 winter was approximately 18,000 Mcf.

The pool, at present, has 114 active input-output wells and five observation wells. Including protective acreage, there are 42,257 acres under lease. Southwest gas is injected into the pool directly from Tennessee Gas Transmission Company's high pressure line.

Due to high pressure and long distance transmission of natural gas, the Menifee Storage Pool is being limited by economic considerations to local distribution use.

The accompanying map and cross section (figure 52) show the Silurian and or Devonian Corniferous immediately underlying the New Albany black shale. The light colored shales overlying the Devonian shale are part of the Waverly Group, which has been used to include the lower Osage sandstones and shales.

Additional Possible Storage Areas

Most of the old producing shallow gas fields of eastern Kentucky, particularly the sand lenses of the Berea, Weir and Big Injun of Osage age, would make ideal storage reservoirs, providing they can be found

STRATIGRAPHIC SECTION
OF
JUDGE'S CHAPEL AREA
Christian Co., Ky.

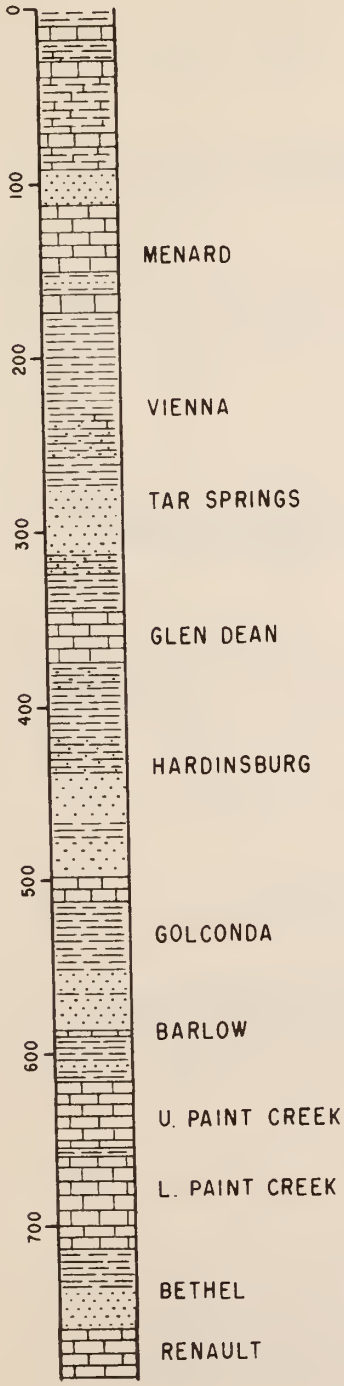


Figure 44.

STRATIGRAPHIC SECTION
OF
GREENVILLE AREA
Muhlenberg Co., Ky.

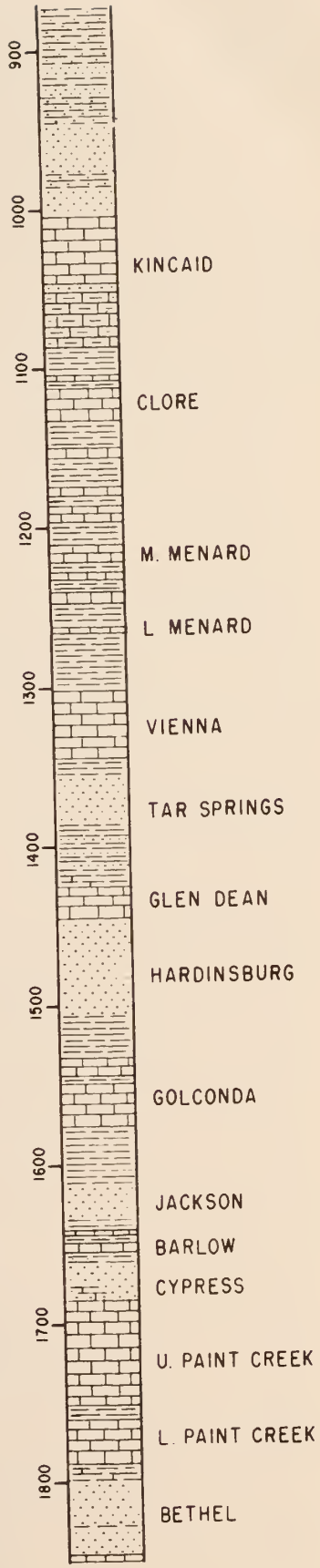


Figure 45.

STRATIGRAPHIC SECTION OF DOE RUN GAS STORAGE FIELD

SYSTEM	SERIES	FORMATION	THICKNESS	GRAPHIC SECTION	LITHOLOGIC DISCRIPTION
RECENT ALLUVIUM			0-23'		
PLEISTOCENE SANDS AND GRAVELS			0-86'		
MISSISSIPPIAN	MERAMEC	ST. LOUIS	50' to 185'		Dense, fine-grained, dark gray, fossiliferous limestone with chert beds near top
		SALEM	20'-65'		Coarse-grained, light gray to tan fossiliferous limestone with shale at base
		WARSAW	135' to 215'		Fine-grained to crystalline, tannish gray to dark gray limestone with scattered shale and fossiliferous beds throughout.
	OSAGE	FT PAYNE	60'-80'		Dense, bluish gray shale with coarse-grained light to bluish gray limestone, siliceous.
		NEW PROVIDENCE	80'-95'		Dense, bluish gray, fossiliferous shale
DEVONIAN		NEW ALBANY	80' to 100'		Dark brown to black, fissile, carbonaceous shale.
	ERIAN	SELLERSBURG	0-18'		Gray, fine-grained, cherty, limestone
	ULSTERIAN	JEFFERSONVILLE	10'-30'		Tan to brown, coarse-grained fossiliferous limestone, tan chert at base
SILURIAN	NIAGARAN	BROWNSPORT GROUP	29'-73'		Coarsely crystalline, light gray, dolomitic limestone
			38'-73'		Dense, dark argillaceous dolomite grading into a light gray, medium crystalline, argillaceous dolomite at base
		LOUISVILLE	32'-41'		Medium crystalline to coarsely crystalline, light gray, dolomitic limestone.
		WALDRON	7'-9'		Dense, green, slightly calcareous shale.
		LAUREL	30'-37'		Dense to medium-grained, light gray to white dolomite
		OSGOOD	9'-12'		Dense, dark gray to red shales
	ALBION	BRASSFIELD	12-15'		light brown, dolomitic lm., white chert
ORDOVICIAN	CINCINNATIAN				

Figure 46

Table 18 - Louisville Gas and Electric Company Storage Fields

Field and Area	Coverage by Acres	Nature of Reservoir	Thickness Ft.	Formation	Capacity MMMcf	Average Depth Ft.	No. of Wells	Maximum Shut-in Pressure, psig
Magnolia Storage Field Hart, Green, Larue Counties, Kentucky	4,600	Plunging Anticline with pinch-out of reservoir beds	15-20	Louisville (Silurian)	3.5	430	48 gas inj. and storage wells	186
Muldraugh Storage Field Meade County, Kentucky	978	Dome	30	Louisville-Laurel (Silurian)	2	500	31 gas inj. and storage wells	242
Doe Run Storage Field Meade County, Kentucky, Harrison County, Indiana	2,480	Elongate anticline (aquifer)	----	Jeffersonville (Devonian) and Brownsport (Silurian)	3.5	550	68 gas inj. and storage wells	280

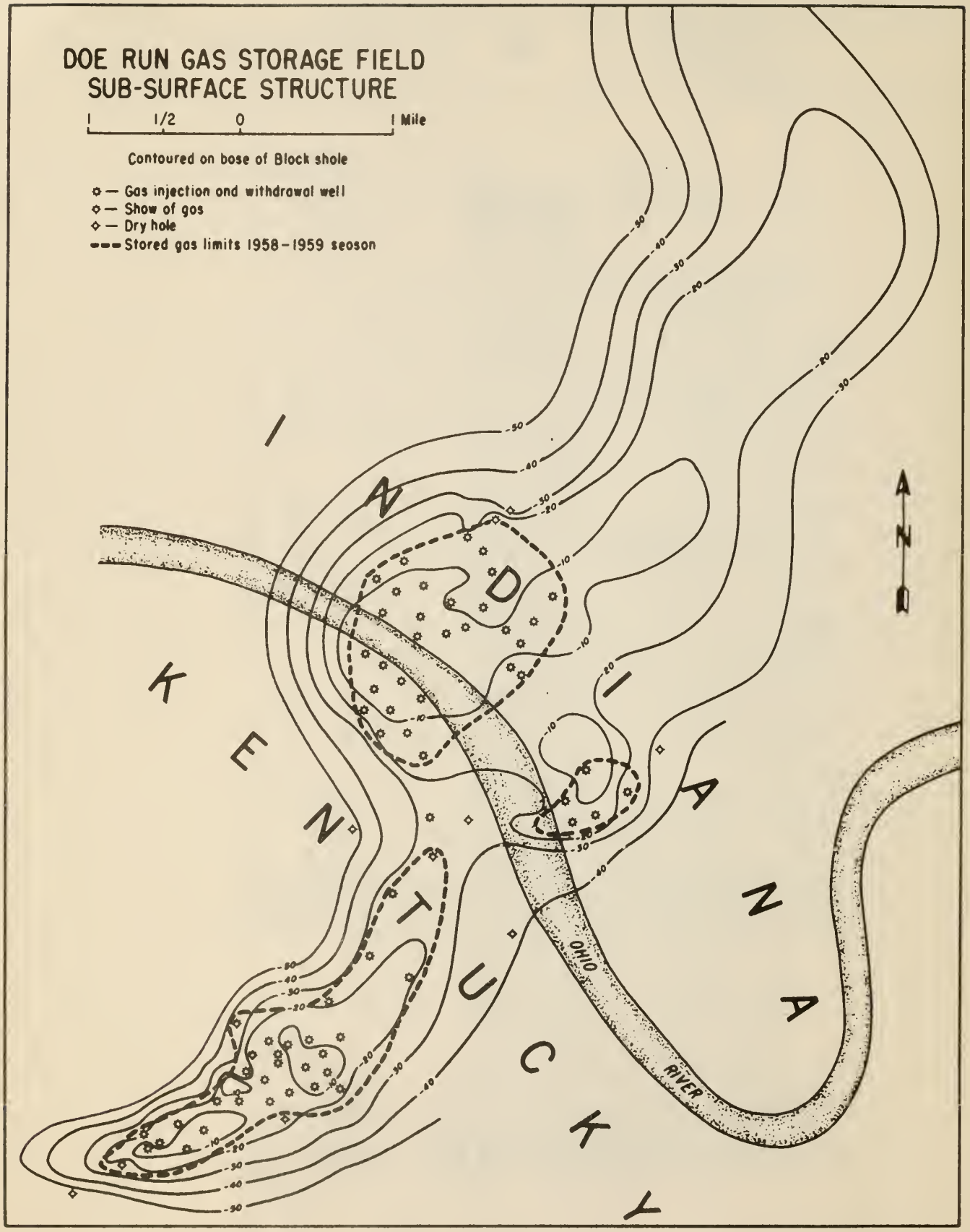
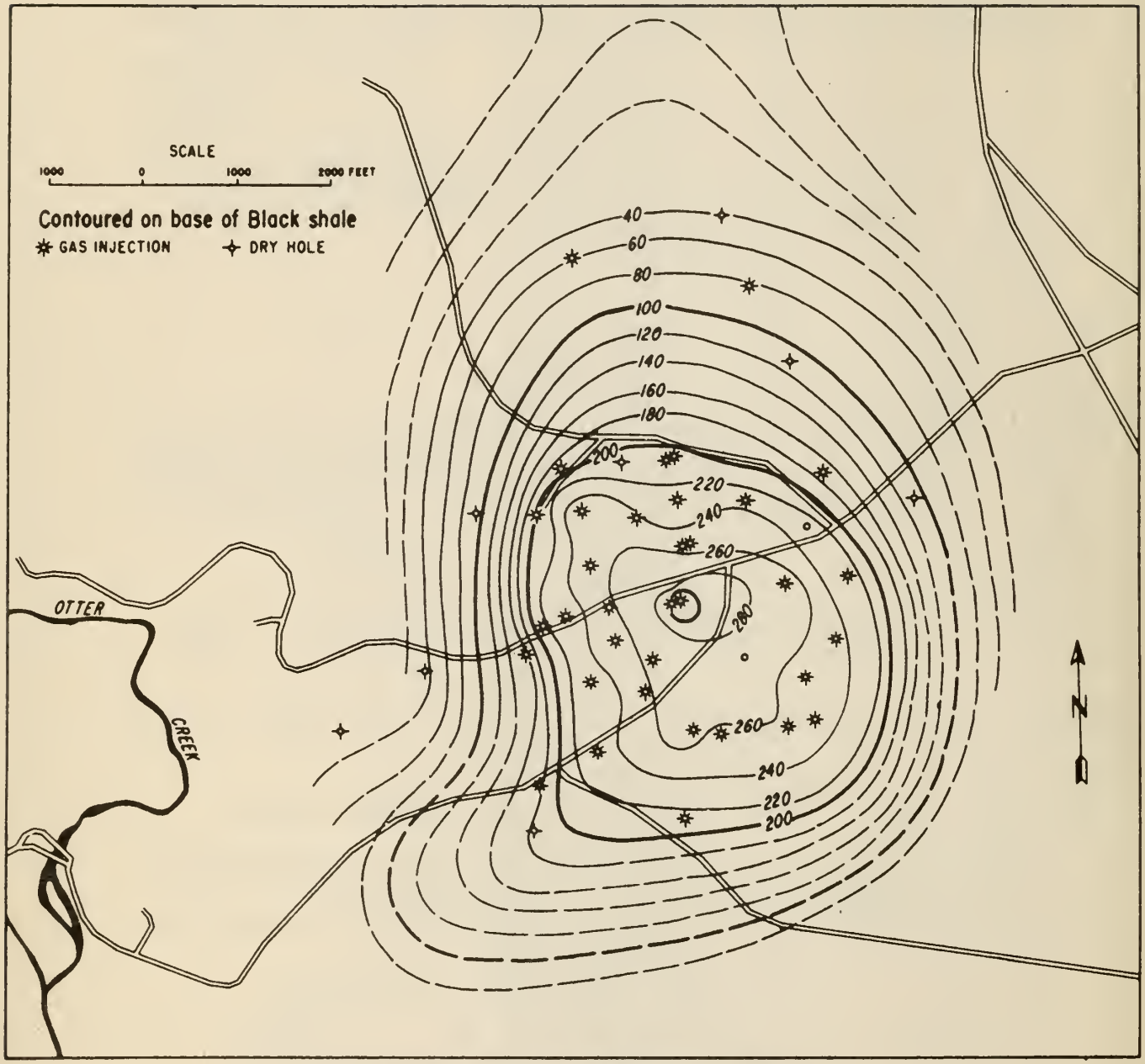

DOE RUN GAS STORAGE FIELD
SUB-SURFACE STRUCTURE
1 1/2 0 1 Mile
Contoured on base of Black shale
— Gas injection and withdrawal well
— Show of gas
— Dry hole
Stored gas limits 1958-1959 season
INDIANA
KENTUCKY
OHIO RIVER
N

Figure 47

STRATIGRAPHIC SECTION OF MULDRAUGH GAS STORAGE FIELD

SYSTEM	SERIES	FORMATION	THICK-NESS	GRAPHIC SECTION	LITHOLOGIC DISCRIPTION
MISSISSIPPIAN			0-20'		Residuol soil
	MERAMEC	WARSAW	200' to 300'		Limestone, tonnish groy to dork groy to block, fine-groined to crystolline with scottered shole ond fossiliferous beds throughout.
	OSAGE		35'-50'		Limestone, dolomitic, gray-brown with o groy, slightly calcareous shale ot base
		NEW PROVIDENCE	104' to 127'		Shole, dense, bluish gray, rare crinoid frogments included.
DEVONIAN	DEVONIAN	NEW ALBANY	76'-112'		Shole, block, fissile, corbonoceous
SIL.	NIAGARAN	LOUISVILLE AND/OR LAUREL	23'-44'		Limestone, dolomitic, white to greenish gray, med. to coorsely xln.
ORDOVICIAN		KNOX?	100'		Debris from frogmenting ond recementotion of Knox dolomite.

Figure 48



STRUCTURE MAP OF MULDRAUGH FIELD

Figure 49.

STRATIGRAPHIC SECTION OF MAGNOLIA GAS STORAGE FIELD

SYSTEM	SERIES	FORMATION	THICKNESS	GRAPHIC SECTION	LITHOLOGIC DISCRIPTION
PENN.		POTTSVILLE	0-30'		Coarse-grained, reddish brown sandstone conglomerate.
MISSISSIPPIAN	MERAMEC	ST. LOUIS	0-20'		Dense, fine-grained, dark gray limestone (Lower part)
		SALEM	0-20'		Coarse-grained, light gray, fossiliferous limestone
		WARSAW	300' to 425'		Fine-grained to crystalline, tannish gray to dark gray limestone with scattered shale beds and fossiliferous beds throughout
	OSAGE	NEW PROVIDENCE	5'-15'		Dense, bluish gray shale.
DEVONIAN		NEW ALBANY	50'-60'		Dark brown to black, fissile, carbonaceous shale.
		SELLERSBURG JEFFERSONVILLE	0-25'		Dense, light brown limestone with white chert throughout
SILURIAN	NIAGARAN	LOUISVILLE	0-75'		Very light green crystalline dolomitic limestone with highly porous beds near top and middle, thin green shales at base
		WALDRON	0-10'		Dark green, calcareous, shale
		LAUREL	25'-60'		Bluish white crystalline dolomitic limestone with oolites found in top two feet.
		OSGOOD	36'		Greenish shales at top grading into reddish shales at base.
	ALBION	BRASSFIELD	30'		Light tan, tightly crystalline dolomite with yellow chert
ORDOVICIAN	CINCINNATIAN				

EXPOSED

Figure 50.

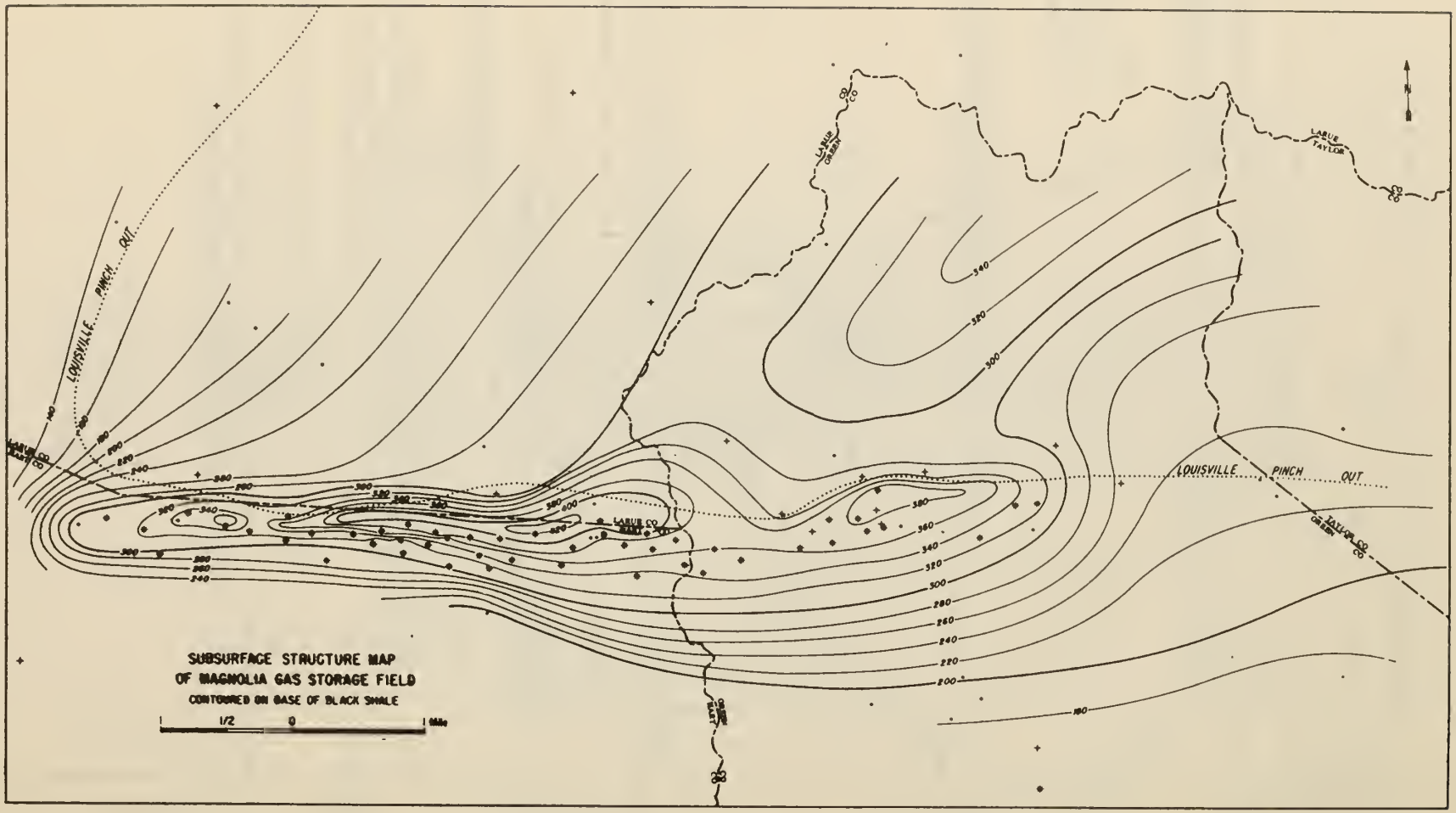
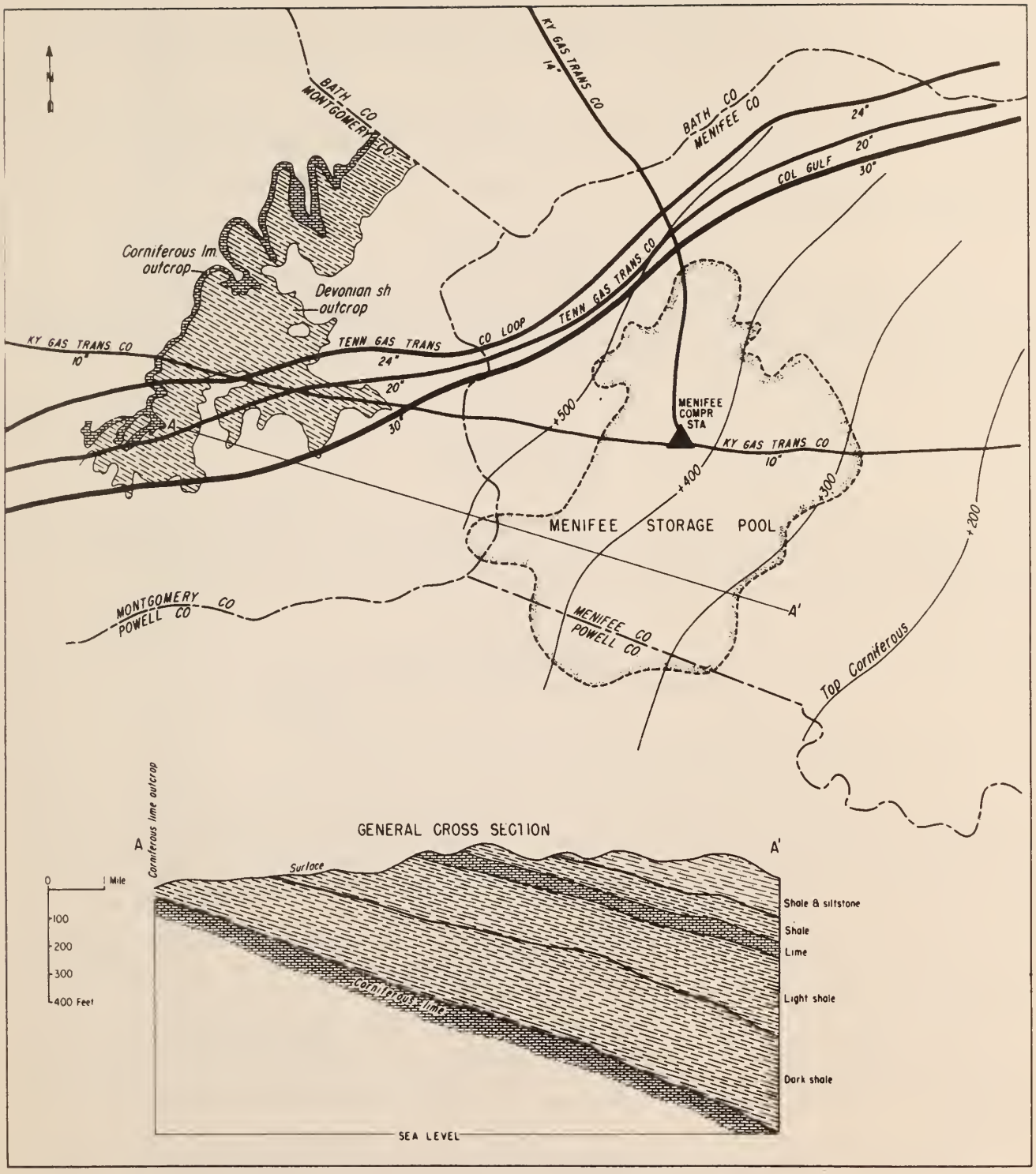

SUBSURFACE STRUCTURE MAP
OF MAGNOLIA GAS STORAGE FIELD
CONTOURED ON BASE OF BLACK SHALE
1/2
0
1 Mile
LOUISVILLE PINCH OUT
LOUISVILLE PINCH OUT
LABUR CO
GREEN CO
TAYLOR CO
N

Figure 51.



MENIFEE GAS STORAGE POOL

Figure 52.

with sufficient porosity and permeability. The shallow Pennsylvanian salt sands would also provide possible storage reservoirs if found with the requisite closure.

Similarly, most of the available storage reservoirs in western Kentucky would be of Mississippian Chester age or shallow Pennsylvanian Sands. The many depleted gas fields scattered through western Kentucky should be investigated further for additional storage space, as most of the Chester Sands meet the requirements for storage reservoirs.

A stratigraphic section of a deep test drilled in Leslie County by United Fuel Gas Company (figure 53) shows some of the deeper formations which may be encountered in this area of the state.

Below the Big Six Sand, which is comparatively shallow in some areas of eastern Kentucky, the storage facilities seem limited.

Acknowledgements

Thanks are due to Ralph Thomas, Texas Gas Transmission Company, Owensboro, Kentucky; Adrian Boyd, Western Kentucky Gas Company, Owensboro, Kentucky; W. B. Maxwell, United Fuel Gas Company, Charleston, West Virginia; Albert L. Bryant, Louisville Gas and Electric Company, Louisville, Kentucky; and several other individuals who have made this gas storage data available.

LOUISIANA

Leo W. Hough
State Geologist

Louisiana is a net producer of gas. All areas of the state are close to the gas fields or pipelines. The state does not need any underground storage reservoirs at this time. The rules and regulations which would govern the gas storage projects would be those of the Department of Conservation.

MARYLAND

Joseph T. Singewald, Jr., Director
Department of Geology, Mines and Water Resources

There is no underground storage of natural gas in Maryland at present.

The Washington Gas Light Company explored the Maryland Coastal Plain in southern Prince Georges County to the north and west of Brandywine and found a structure with an area of 8,000 acres, about 6 miles long and 2 miles wide, with a closure of 146 feet in which the proposed storage sand is 30 feet thick and its crest is at an elevation of 1,114 feet below sea level. The storage sand is overlain by a clay bed with a minimum thickness of 20 feet. The hydrostatic pressure in the sand is 510 psi. The sand is in the lower part of the Lower Cretaceous Patuxent Formation.

In 1954 the Washington Gas Light Company unsuccessfully attempted to have a bill enacted permitting it to condemn property in the area of the structure to obtain gas storage rights. Efforts to secure such legislation in succeeding sessions of the Legislature have also been unsuccessful.

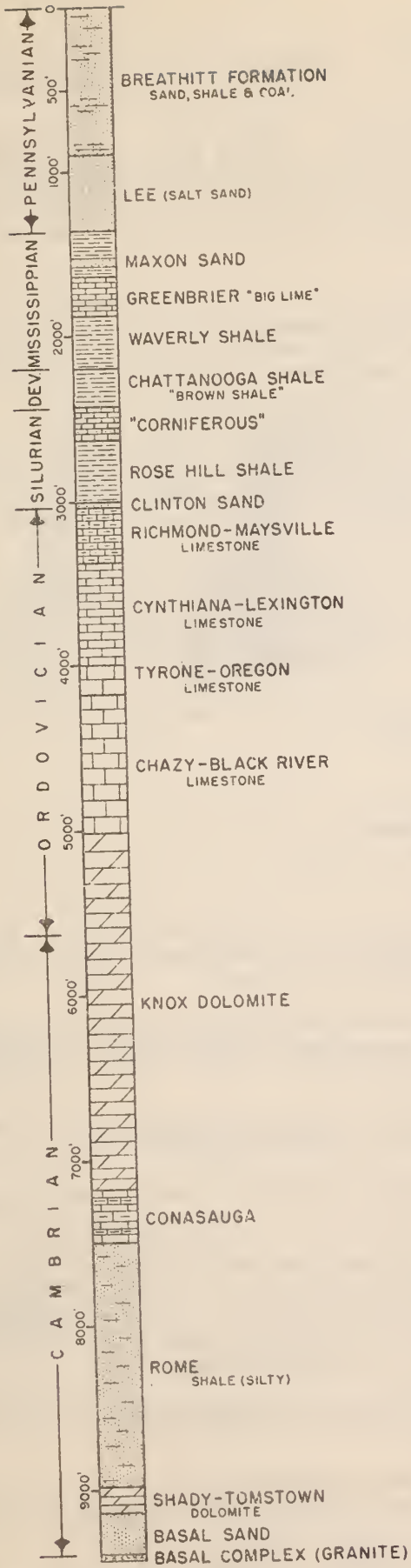
In 1957, however, a bill was enacted applying only to Prince Georges County authorizing natural gas storage in a structure overlain by at least 25 feet of clay having such geologic properties as will, in the opinion of the Department of Geology, Mines and Water Resources, and concurred in by the Water Pollution Control Commission, constitute sufficient protection to the potable fresh water supplies existing in any aquifer.

Late in 1957 the Washington Gas Light Company successfully tested the adequacy of the overlying clay bed by injecting inert gas into the top 400 acres of the structure.

In 1959 a bill was introduced authorizing the acquisition by eminent domain of gas storage rights in geologic strata not less than 1,000 feet deep over a maximum surface area of 12,000 acres and limited to

STRATIGRAPHIC SECTION OF UNITED FUEL GAS COMPANY'S BASEMENT TEST

Leslie Co., Ky.



T. D. = 9,432 Feet

Figure 53

within prescribed boundaries in the Brandywine area in Prince Georges County, providing the gas company shall have obtained storage rights by agreement with at least 75 percent of the landowners in the project area controlling 75 percent of the acreage. This bill was introduced after an extensive educational and advertising campaign by the Washington Gas Light Company. The bill was held in Committee until the last days of the session and then reported unfavorably.

Until the discovery of the closed structure in the Maryland Coastal Plain by the Washington Gas Light Company, it was generally believed there was no reversal in the prevailing southeasterly dip of the Coastal Plain sediments. Now that a reversal has been proven, there is the probability that with intensive exploration in areas where there appears to be merely a flattening of the dip other closed structures may be discovered.

There are two producing gas fields in western Maryland in Garrett County, the westernmost county in the State. The older Mt. Lake Park Gas Field may not be useable for storage, because many of the wells drilled in it were abandoned without sealing and plugging before operators were required to post bond to guarantee proper abandonment. The other gas field, the Accident Field, will become available for storage.

There are anticlines of Appalachian structures in Garrett and Allegany Counties and western Washington County along the axis of which there may be closures. At present there is interest and leasing activity in these counties east of the two gas fields. Future explorations and developments may disclose other structures in which natural gas can be stored.

Between eastern Washington County and the Fall Line the possibilities for natural gas storage are unfavorable. Most of this area is underlain by crystalline rocks.

MASSACHUSETTS

C. Wroe Wolfe, Chairman
Department of Geology, Boston University

The boundaries of the various lithologic types must be considered extremely approximate in the generalized geology map of Massachusetts (figure 54), and the rocks may vary considerably in any one type. More specific information of value can be obtained only by localized investigation.

Province 1. - In this area are highly sheared but not recrystallized Cambrian and Ordovician rocks. The slates in this belt could be easily mined to provide large openings which would be tight at depths of several hundreds of feet. The slates are not strategically located.

Province 2. - The Cambrian through Devonian rocks have been highly metamorphosed and contain some granites and pegmatites. They are difficult to mine and not strategically located.

Province 3. - The Middle to low grade metamorphic Silurian and Devonian rocks are not strategically located. A few old mines exist but they are probably inadequate for fuel storage.

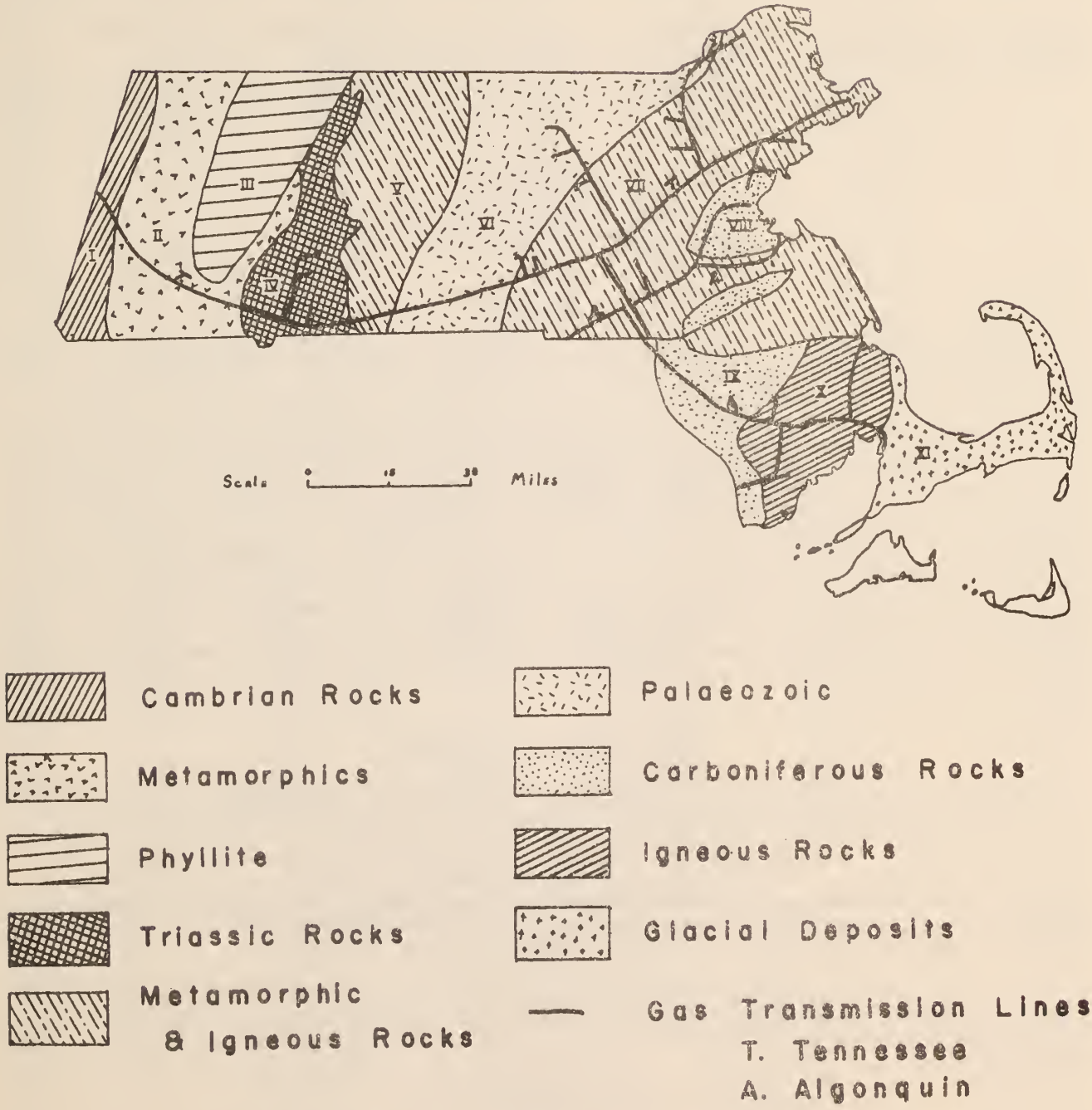
Province 4. - This is the Triassic Basin of intercalated basaltic flows and permeable red sandstones, conglomerates, and siltstones. These vesicular basalts could hold some gas as could the sandstones. The best openings would be man-made between lava flows by removal of sandstones or siltstones between the two impermeable horizons. The province is one of the most suitable areas for storage in Massachusetts because of favorable rock structures and strategic location near the Springfield area.

Province 5. - The metamorphic and igneous rocks are not suitable nor strategically located for fuel storage.

Province 6. - The late Paleozoic middle and low grade metamorphics and sediments are strategically located near Worcester, and suitable openings could be made near that area if proper precautions were taken. No suitable openings now exist.

Province 7. - These igneous and metamorphic rocks are not of much strategic importance. No openings exist, and new ones could be opened only with considerable difficulty.

Generalized Geology and the Major Gas Transmission Lines



# of Massachusetts

Figure 54

Province 8. - The Devonian or Carboniferous siltstones, conglomerates, tillites, lavas, and tuffs are of great importance strategically. There are no existing openings. New openings could be made quite readily in the Cambridge Formation.

Province 9. - The carboniferous conglomerates, sandstones, siltstones, shales, and coal beds are strategically important. Some old coal mine openings exist but are probably not serviceable. New openings could be readily made.

Province 10. - This province is mostly granite and is strategic to Fall River and New Bedford. Openings could be made more easily in province 9 which is sufficiently near.

Province 11. - The glacial deposits are strategically and structurally unsatisfactory for gas storage.

MICHIGAN

Gordon H. Hautau
Geological Survey Division
Michigan Department of Conservation

General

Underground storage of natural gas is basically a means of smoothing out the demand cycle by storing gas in low demand or off-peak periods for use during high demand or peak load intervals. The enormous volumes of gas delivered by modern large diameter, "Big Inch" transmission lines have made it economically impractical to provide adequate surface storage for the large volumes necessary to meet the needs of a properly balanced system. Adequate storage facilities near marketing centers have made many of the modern long distance pipeline systems economically feasible. Storage provides steady year around deliveries and assures maximum utilization of these costly facilities. From the petroleum conservation standpoint, underground storage has made economically feasible the construction of many casinghead gas plants for the utilization of flare gas produced as a by-product of oil production by providing a steady year around market. The pipeline systems have been able to upgrade large volumes of gas delivered in the summer months that would otherwise be marketed as dump gas. The gas industry in Michigan, due to the extreme seasonal variation in temperature and associated variation in demand, has of necessity been alert to the need for and quick to recognize the value of underground gas storage in its operations. Michigan has been one of the leading states in the development and efficient utilization of underground gas storage. This is true not only as to the number of projects but in relation to the volume of gas moving into and out of storage.

History of Storage in Michigan

Injection of gas into underground storage reservoirs in Michigan was commenced in 1941 at the Austin Stray Sandstone Gas Field in central Michigan. The record shows relatively small volumes of gas were injected and withdrawn during the first six years. The year 1947 brought a marked increase in both injection and withdrawals. The year ended with an excess of withdrawals over input and touched off a rapid expansion of the industry. The Gas Section of the Michigan Public Service Commission compiles an annual statistical report on natural gas production, transmission, and storage for the State of Michigan. These reports were used to compile the following statistical record on the underground storage of gas and related data for the State of Michigan from 1940 through 1959 (see table 19).

The American Gas Association through its committee on underground storage has since 1950 annually compiled a statistical report on the underground storage of gas in the United States. These reports provide the basic information for the following statistical record on underground storage facilities in Michigan (see tables 20 and 21).

Gas Production in Michigan

The early records on gas production in Michigan are unreliable being in large measure based on estimates of the observer. The records of the Geological Survey Division of the Michigan Department of Conservation are based on official reports to the State Revenue Tax Division beginning in 1929. The

Table 19 - Underground Storage of Gas and Related Data

Year	Michigan Production	Imported	Net Gas Marketed	Injected	Withdrawn	Net in Storage
1940	12,198,070	22,273,874	34,471,944	-	-	-
1941	13,519,376	24,175,352	36,751,591	885,095	213	884,882
1942	17,118,144	27,295,451	42,325,485	2,056,600	0	2,941,482
1943	19,274,140	36,291,748	54,272,311	1,271,728	9,930	4,203,280
1944	20,167,570	37,700,885	57,610,797	384,404	282,421	4,305,263
1945	21,870,228	39,773,139	61,336,170	831,713	730,784	4,406,192
1946	21,943,415	49,607,119	71,944,751	1,601,213	1,775,329	4,232,076
1947	17,658,592	61,270,840	82,715,855	5,543,409	9,198,174	577,310
1948	17,265,422	71,481,505	78,192,980	21,914,738	11,264,367	11,227,681
1949	13,622,697	82,922,339	86,392,863	26,348,080	16,160,601	21,415,160
1950	11,734,605	133,529,702	135,096,129	35,706,533	25,731,341	31,390,353
1951	9,978,773	167,031,723	157,469,873	53,544,707	34,176,807	47,363,196
1952	7,978,273	186,115,994	167,463,042	60,220,723	35,207,429	63,695,363
1953	6,625,664	194,770,364	183,405,967	50,179,966	39,974,261	73,901,067
1954	5,363,956	189,492,738	191,964,112	54,530,344	57,016,292	71,415,118
1955	6,632,635	199,054,362	212,753,893	67,190,088	74,279,107	64,326,079
1956	8,346,674	256,781,137	240,580,394	95,735,492	71,231,498	88,830,074
1957	6,130,560	305,181,547	274,639,782	108,363,029	72,589,015	124,604,088
1958	10,618,982	283,253,617	303,838,514	90,216,299	105,105,030	109,715,357
1959	15,424,483	330,524,979	336,981,675	123,871,480	115,719,361	120,606,183

Table 20 - Underground Storage of Gas by Pools

Year	Pools	Wells	Compressor Stations		Underground Storage Data for Year Ending 10-31		
			No.	H.P.	Input (Mcf)	Output (Mcf)	Max. Day (Mcf)
1950	5	523	2	22,960	34,462,105	14,347,716	298,408
1951	6	591	2	36,180	48,187,208	37,189,178	546,178
1952	11	747	2	38,680	64,959,055	36,686,070	585,452
1953	12	908	2	38,680	55,688,240	39,436,949	619,848
1954	12	910	2	38,680	61,705,111	49,327,206	752,183
1955	12	911	2	38,680	68,238,585	62,897,635	882,342
1956	13	951	3	58,680	93,451,820	88,605,217	1,052,083
1957	17	1,027	3	65,480	110,279,077	65,136,585	1,102,283
1958	18	1,084	3	65,480	93,885,973	84,956,649	1,424,629
1959	19	1,124	3	85,480	123,109,972	114,151,614	1,606,686

Table 21 - Underground Storage of Gas 1950-1959

Year	Gas in Storage as of 12-31			Ultimate Capacity (Mcf)
	Native (Mcf)	Stored (Mcf)	Total (Mcf)	
1950			32,301,000	57,083,165
1951			42,648,000	67,037,615
1952	93,244,088	38,439,993	131,684,081	223,181,545
1953	94,153,023	99,956,977	194,110,000	291,842,754
1954	110,319,757	102,883,370	213,203,127	304,861,531
1955	110,319,757	95,777,392	206,097,149	304,801,531
1956	111,731,763	122,359,840	234,091,603	316,454,781
1957	118,972,369	159,134,575	278,106,944	363,411,570
1958	122,688,697	149,127,851	271,816,548	383,671,390
1959	127,099,825	158,159,611	285,259,436	397,498,020

Table 22 - Annual Gas Production By Formations (Mcf)
January 1, 1925 to January 1, 1960

Year	Drift	Stray-Marshall	Berea	Antrim	Traverse	Dundee-Reed City	Detroit River	Salina-Niagaran	Trenton-Black River	Yearly Totals
1925										
1926										
1927										
1928										
1929						1,887,732		74,867		1,962,599
1930						2,319,620		49,930		2,369,550
1931		46,232				536,629		11,648		594,509
1932		567,039				865,120				1,432,159
1933		675,517				1,021,671				1,697,188
1934		1,713,175			3,744	1,291,166				3,008,085
1935		2,697,388			12,730	2,843,737				5,553,855
1936		4,955,999	53,005		12,000	1,843,722				6,864,726
1937		7,415,831	447,485		8,232	1,439,296				9,310,844
1938		7,291,945	309,352		12,222	1,617,990		1,000		9,232,509
1939		8,408,308	581,234		24,710	1,117,420		5,331		10,137,003
1940		9,421,375	1,304,802		1,730,848	1,655,340		13,999		14,126,364
1941		11,385,657	1,052,286		1,280,257	1,362,264		12,000		15,092,464
1942		15,162,159	1,448,001		492,919	627,910		18,305		17,749,294
1943		17,605,027	1,258,438		212,108	487,605		18,242		19,581,420
1944		16,924,771	797,304		-	3,514,391		17,437		21,253,903
1945		18,365,481	660,403		-	4,258,278		14,386		23,298,548
1946		19,067,396	553,965		-	3,936,936	210,827	5,371		23,774,495
1947		19,817,437	250,850	30,321	-	3,064,695	310,584	481,038		23,954,925
1948		14,952,235	1,438	8,604	822,357	2,530,639	152,187	2,902,127		21,369,587
1949	8,020	8,015,131	804	13,570	591,647	1,920,088	120,165	3,990,822		14,660,247
1950		5,035,523	48,988	12,413	499,510	1,922,979	1,348,702	3,745,909		12,614,024
1951		3,161,518	369,641	7,787	1,027,456	977,435	1,617,414	3,363,244		10,524,495
1952		3,058,853	235,929	13,871	304,497	938,184	1,460,215	2,666,188		8,677,737
1953		3,720,281	152,547	14,027	17,182	812,080	1,298,275	1,075,593		7,089,985
1954		3,057,274	109,097	7,528	64,852	710,900	1,272,651	465,148	10,725	5,698,175
1955		2,378,082	54,582	8,289	31,671	623,664	1,432,635	1,202,718	1,056,056	6,787,697
1956		1,913,078	39,493	11,084	13,376	540,718	1,525,523	2,713,634	2,084,027	8,840,933
1957		1,031,520	26,294	11,094	13,062	444,272	2,326,744	1,617,909	1,168,918	6,639,813
1958		837,548	19,684	11,307	73,297	335,147	3,604,884	4,863,216	1,219,295	10,964,378
1959		674,191	8,032	14,912	135,217	343,265	3,649,466	9,720,047	1,081,097	15,626,227

Table 23 - Cumulative Gas Production by Formations (Mcf)
January 1, 1925 to January 1, 1960

Year	Drift	Stray-Marshall	Berea	Antrim	Traverse	Dundee Reed City	Detroit River	Salina-Niagaran	Trenton-Black River	State Totals
1925										
1926										
1927										
1928										
1929						1,887,732		74,867		1,962,599
1930						4,207,352		124,797		4,332,149
1931		46,232				4,743,981		136,445		4,926,658
1932		613,271				5,609,101		136,445		6,358,817
1933		1,288,788				6,630,772		136,445		8,056,005
1934		3,001,963			3,744	7,921,938		136,445		11,064,090
1935		5,699,351			16,474	10,765,675		136,445		16,617,945
1936		10,655,350	53,005		28,474	12,609,397		136,445		23,482,671
1937		18,071,181	500,490		36,706	14,048,693		136,445		32,793,515
1938		25,363,126	809,842		48,928	15,666,683		137,445		42,026,024
1939		33,771,434	1,391,076		73,638	16,784,103		142,776		52,163,027
1940		43,192,809	2,695,878		1,804,486	18,439,443		156,775		66,289,391
1941		54,578,466	3,748,164		3,084,783	19,801,707		168,775		81,381,855
1942		69,740,625	5,196,165		3,577,662	20,429,617		187,080		99,131,149
1943		87,345,652	6,454,603		3,789,770	20,917,222		205,332		118,712,569
1944		104,270,423	7,251,907		3,789,770	24,431,613		222,759		139,966,472
1945		122,635,904	7,912,310		3,789,770	28,689,891		237,145		163,265,020
1946		141,703,300	8,466,275		3,789,770	32,626,827	210,827	242,516		187,039,515
1947		161,520,737	8,717,125	30,321	3,789,770	35,691,522	521,411	723,554		210,994,440
1948		176,472,972	8,718,563	38,925	4,612,127	38,222,161	673,598	3,625,681		232,364,027
1949	8,020	184,488,103	8,719,367	52,495	5,203,774	40,142,249	793,763	7,616,503		247,024,274
1950	8,020	189,523,626	8,768,355	64,908	5,703,284	42,065,228	2,142,465	11,362,412		259,638,298
1951	8,020	192,685,144	9,137,996	72,695	6,730,740	43,042,663	3,759,879	14,725,656		270,162,793
1952	8,020	195,743,997	9,373,925	86,566	7,035,237	43,980,847	5,220,094	17,391,844		278,840,530
1953	8,020	199,464,278	9,526,472	100,593	7,052,419	44,792,927	6,518,369	18,467,437		285,930,515
1954	8,020	202,521,552	9,635,569	108,121	7,117,271	45,503,827	7,791,020	18,932,585	10,725	291,628,690
1955	8,020	204,899,634	9,690,151	116,410	7,148,942	46,127,491	9,223,655	20,135,303	1,066,781	298,416,387
1956	8,020	206,812,712	9,729,644	127,494	7,162,318	46,668,209	10,749,178	22,848,937	3,150,808	307,257,320
1957	8,020	207,844,232	9,755,938	138,588	7,175,380	47,112,481	13,075,922	24,466,846	4,319,726	313,897,133
1958	8,020	208,681,780	9,775,622	149,895	7,248,677	47,447,628	16,680,806	29,330,062	5,539,021	324,861,511
1959	8,020	209,355,971	9,783,654	164,807	7,383,894	47,790,893	20,330,272	39,050,109	6,620,118	340,487,738

Geological Survey's annual Summary of Operations for Oil and Gas Fields of Michigan is a valuable source for gas production statistics for individual fields, counties, and formations.

All currently active Michigan storage reservoirs have been dry natural gas reservoirs. A study of the annual gas production (table 22) and accumulative gas production data by formations (table 23) indicates why a majority of the existing storage reservoirs are in the Stray-Marshall formations of the Mississippian system. The record shows that the Stray-Marshall accounted for approximately 75% of the state's cumulative gas production through 1949. The tables also show that potential future storage projects are developing in the Salina-Niagaran and Trenton-Black River Formation presently accounting for a major share of the state's gas production.

The names and location of active gas fields, gas storage reservoirs, and major pipelines of Michigan are shown in figure 55. Figure 56 is an index map showing the location and status of twenty-five known storage projects.

Stratigraphy and Structural Geology of Michigan in Reference to Gas Storage

Figure 57 is a map showing the areal distribution of the various bedrock units in Michigan. Figure 58 shows the general columnar section for Michigan with information pertaining to the gas-producing formations.

Table 24 - Status of Gas Storage Reservoirs in Michigan
December 1, 1960

	Reservoir Name	Date First Storage	Present Status	Stratigraphic System
1	Austin	1941	O	Mississippian
2	Boyd	-	P	Silurian
3	Broomfield-Deerfield	1957	D	Mississippian
4	Coldwater	1956	D	Mississippian
5	Cranberry Lake	1947	O	Mississippian
6	Croton	1957	O	Mississippian
7	Edmore-Richland	-	D	Mississippian
8	Evart	-	D	Mississippian
9	Freeman-Lincoln	1950	O	Mississippian
10	Goodwell	1948	O	Mississippian
11	Howell	-	P	Silurian
12	Marion-Winterfield	1947	O	Mississippian
13	North Hamilton	-	D	Mississippian
14	Northville	-	P	Ordovician
15	Orient	1951	O	Mississippian
16	Overisel	1961	O	Silurian
17	Peters	-	P	Silurian
18	Reed City	1947	O	Mississippian
19	Riverside	1952	O	Mississippian
20	Rolland	1957	D	Mississippian
21	Salem	-	P	Silurian
22	Shaver-Crystal (New Haven)	1958	D	Mississippian
23	Six Lakes	1953	O	Mississippian
24	Winfield	1950	D	Mississippian
25	Woodville (Norwich)	1951	O	Mississippian

Numbered alphabetically to conform with numbered location map shown on figure 56,

Reservoir status symbols: O = Operating
D = Developing
P = Proposed

The Michigan Stray-Upper Marshall Sandstone, Basal Salina-Niagaran Section and the Trenton-Black River Formations are presently the three major gas producing formations with respect to either existing gas storage reservoirs, current gas production and reserves, or prospective developments of sizeable future natural gas reserves in reservoirs adaptable to gas storage purposes. These three formations had produced approximately 75 percent of the total gas production of record to January 1, 1960. A brief review of all gas-producing formations of Michigan with emphasis on those of greatest importance from the standpoint of gas storage should be pertinent. The formations are presented in the order of their increasing age. Figure 59 and figure 60 are maps showing oil- and gas-producing areas of the state by formation.

Glacial Drift (Pleistocene)

Drift gas occurs over wide areas of the state, and small quantities have been utilized for domestic or noncommercial purposes. The gas migrates into porous sections of the drift from underlying bedrock units and may accumulate where conditions are favorable in low pressure traps. Drift gas has frequently been reported by water well drillers and is often considered a fire hazard in urban areas. The drift gas has not been utilized commercially and is of minor importance from the standpoint of prospective reserves and potential gas storage development. The small size of the reservoirs, inadequate sealing of cap rock, and low pressure in associated aquifers are all factors unfavorable for gas storage development.

Saginaw Sandstone (Pennsylvanian)

The Saginaw Sandstone has produced small volumes of gas in Edenville Township of Midland County, but reserves are small and of no great commercial significance. The low capacity of the known reservoirs and relatively low indicated safe operating pressure are limiting factors unfavorable to utilization of reservoirs in gas storage operations.

Stray-Marshall (Mississippian)

The Michigan Stray-Upper Marshall Sandstones have accounted for over 61% of the state's recorded gas production as of January 1, 1960. The Michigan Stray sands are similar in lithology to the underlying Upper Marshall Sandstones and occur as a series of sand lenses or bars separated by thin interfingering beds of shale or dolomite. These beds of shale and dolomite may be absent in structurally higher sections of the fields permitting hydraulic communication between lenses. Accumulations are in anticlines with thickest and cleanest pays over the highest part of the structures in most instances.

All of the larger Stray gas fields have been converted or are being converted to gas storage including Austin, Broomfield-Deerfield, Coldwater, Cranberry Lake, Croton, Edmore-Richland, Evart, Freeman-Lincoln, Goodwell, North Hamilton, Marion-Winterfield, Orient, Reed City, Riverside, Rolland, Shaver-Crystal, Six Lakes, Winfield, and Woodville.

Extensive areas underlain by the Stray-Marshall Sandstones are inadequately explored and may contain sizeable reserves. The successful conversion of older Stray-Marshall reservoirs to gas storage use suggests new fields will soon be added to the existing gas storage networks.

Berea (Mississippian)

The typical Berea Sandstone Formation of eastern Michigan thins to the westward and occurs only sporadically over the central part of the basin. A sandy oolitic limestone or dolomite appears in approximately the same stratigraphic position in western Michigan. The Berea pay in eastern Michigan is normally a dolomitic sandstone or sandstones separated by thin beds of shale. The eastern producing area extends in a broad belt from southern Ogemaw County southward into Genesee and Lapeer Counties. The western Michigan producing area is a somewhat narrower belt from ten to thirty miles wide and one hundred miles long extending from southwestern Kent County northward into northern Oceana County. The western Michigan pays occur as sandy oolitic limestones or dolomites. Anticlinal accumulations of oil and gas are found in both areas along the smaller, localized, lenticular, permeability traps. The formation is considered adaptable to gas storage operations by conversion of old gas fields to storage, although the reservoirs are not large. Among the Berea fields that may prove of interest for gas storage, now at or near abandonment, are Clayton and Deep River in eastern Michigan and Ravenna and Cedar Creek in the western Michigan area. It is highly improbable that all commercial Berea gas fields will be limited to the two known producing areas. The low permeability of the Berea in other areas and associated low deliverability tend to reduce its potential value for utilization in gas storage operations.

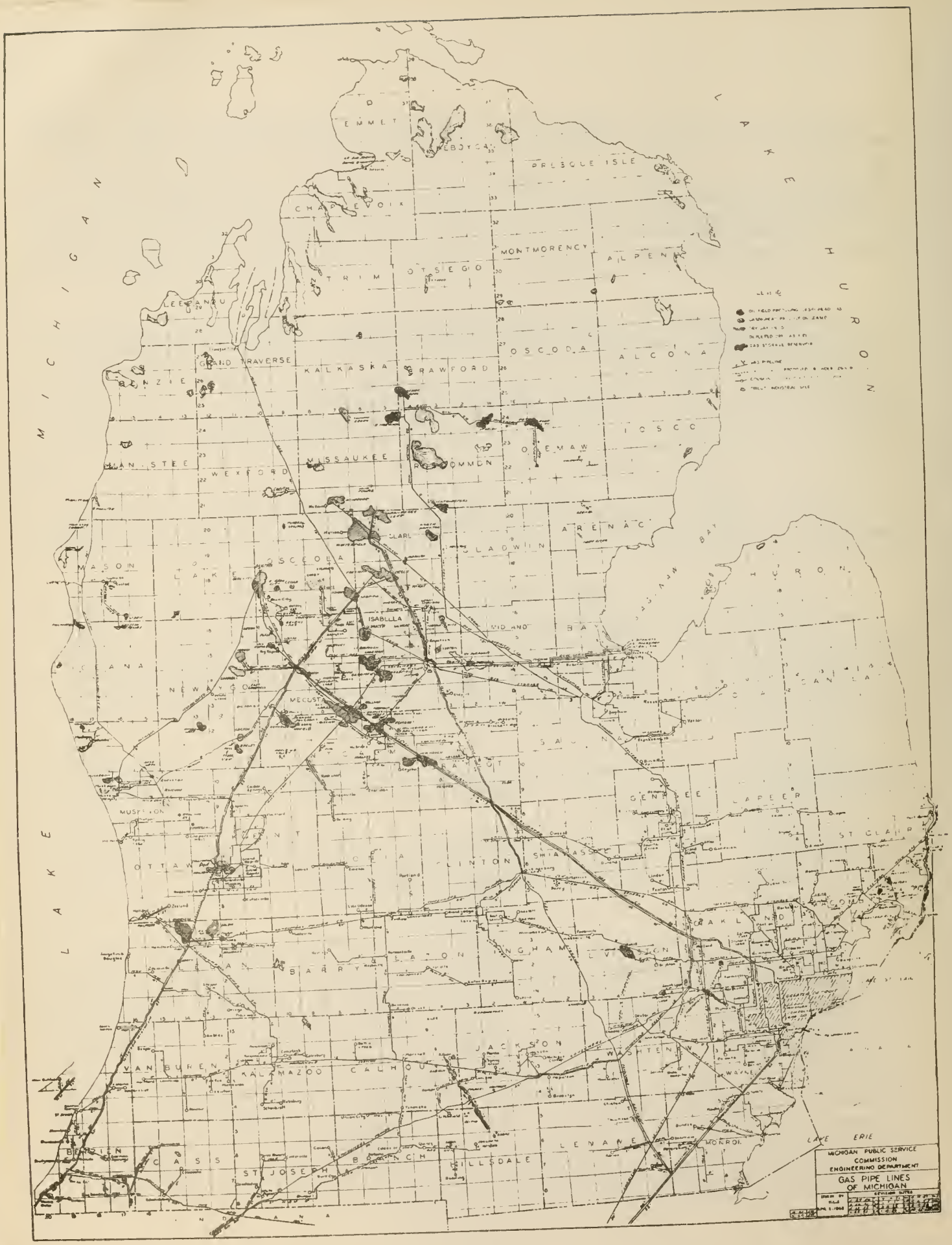
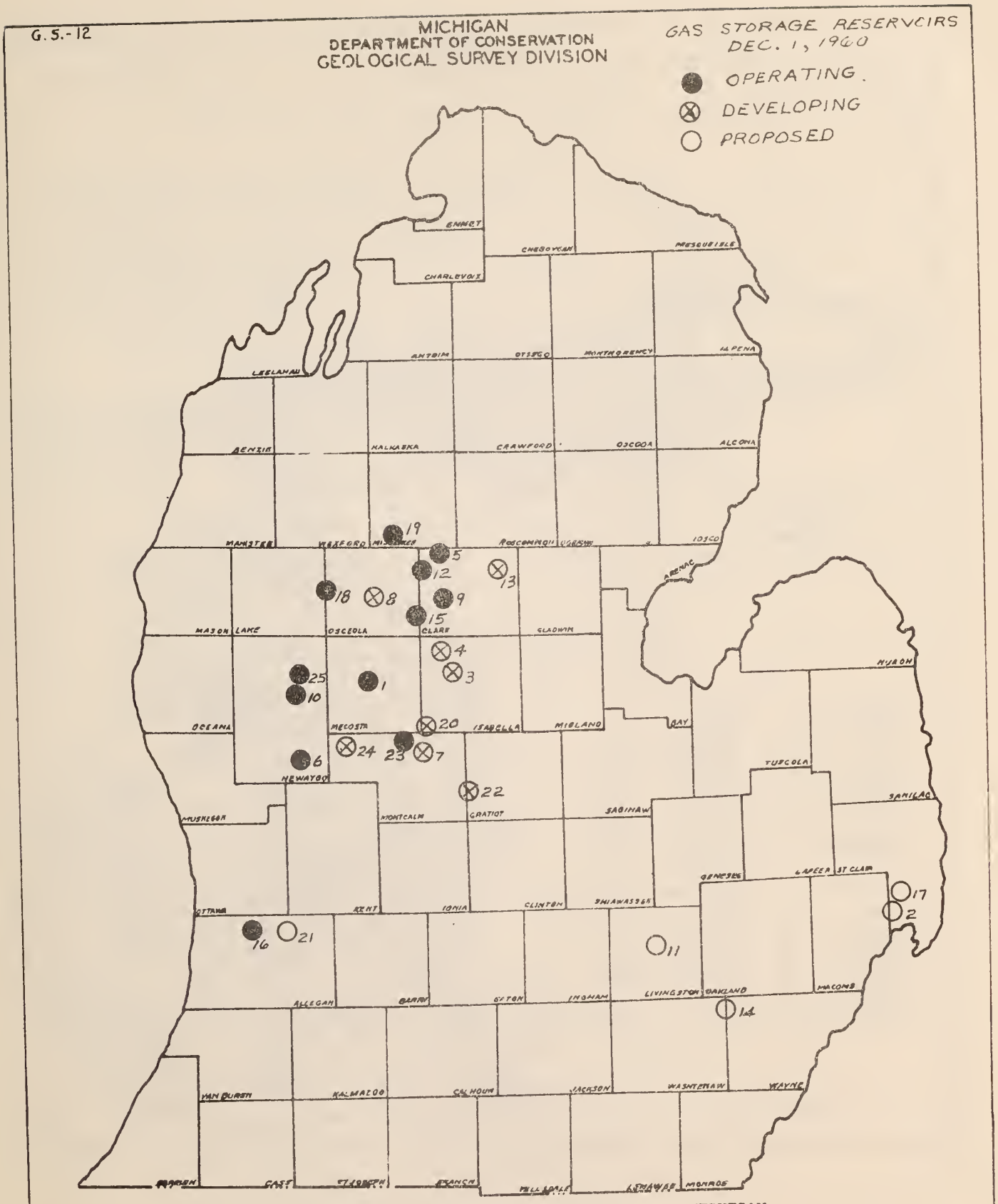

LAKE MICHIGAN
LAKE HURON
LAKE ERIE
EMMET
PRESQUE ISLE
CHARLEVOIX
MONTMORENCY
ALPENA
ANTRIM
OTSEGO
LEELANAU
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
BENZIE
IOSCO
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
ARENAC
CLARE
GLADWIN
MASON
LAKE
OSCEOLA
HURON
ISABELLA
MIDLAND
BAY
OCEANA
NEWAYGO
MECOSTA
SAGINAW BAY
SAGINAW
GENESEE
LAPEER
ST CLAIR
MUSKEGON
GENT
OTTAWA
IONIA
CLINTON
SHIAWASSEE
OAKLAND
LEGAN
BARRY
EATON
INGHAM
LIVINGSTON
JACKSON
WASHTENAW
VAN BUREN
KALAMAZOO
CALHOUN
WAYNE
BERRIEN
CASS
ST JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE
MICHIGAN PUBLIC SERVICE COMMISSION
ENGINEERING DEPARTMENT
GAS PIPE LINES OF MICHIGAN

Figure 55



UNDERGROUND GAS STORAGE RESERVOIRS IN MICHIGAN

FIGURE 56.

MICHIGAN
DEPARTMENT OF CONSERVATION
GEOLOGICAL SURVEY DIVISION
CANADA
MINNESOTA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
DOMINION OF CANADA
WHITEFISH BAY
INDIANA
Geological Map of Michigan
Helen M. Martin
1955
A revision of the Centennial Geological Map
Legend
Pennsylvanian
Red Beds, Grand River Group Pgr
Saginaw Parma Group Ps
Mississippian
Bayport ls Mb
Michigan series Mm
Napoleon-Marshall ss Mnm
Coldwater sh Mc
Berea-Bedford Mbb
Ellsworth sh Me
Mississippi-Devonian
Antrim sh DMa
Devonian
Traverse fm DT
Rogers City ls Drc
Dundee ls Dd
Detroit River group Ddr
Bois Blanc fm Dbb
Sylvania ss Ds
Garden Island fm Dgl
Mackinac breccia D-Sm
Silurian
St. Ignace fm
Pointe aux Chenes fm Sp
Engadine dol Se
Manistique series Sm
Burnt Bluff ls Sbb
Mayville fm Sme
Ordovician
Richmond OR
Trenton OT
Black River OBR
Ozarkian
Hermansville
Cambrian
Lake Superior ss CLS
Algonkian
Killarney granite Aky
Keweenawan Ak
Freda ss, Nonesuch shales Aku
Huronian Ah
Huronian iron fms
Archean
Laurentian ARL
Keewatin ARK

Figure 57.

GENERALIZED COLUMNAR SECTION OF MICHIGAN

MICHIGAN GEOLOGICAL SURVEY DIVISION

SYSTEM, SERIES		FORMATION, GROUP	LITHOLOGY	THICKNESS	
RECENT					
PLEISTOCENE		GLACIAL DRIFT	SAND, GRAVEL, CLAY, boulders, marl	0-1000	
"PERMO-CARBONIFEROUS"		"RED-BEDS"	SHALE, CLAY, SANDY SHALE, gypsum		
PENNSYLVANIAN		GRAND RIVER	SANDSTONE, sandy shale	80-95	
		SAGINAW	SHALE, SANDSTONE limestone coal	20-535	☼
MISSISSIPPIAN		BAY PORT	LIMESTONE SANDY OR CHERTY LIMESTONE, SANDSTONE	2-100	
		MICHIGAN	SHALE, gypsum, anhydrite, sandstone	0-500	
		"MICHIGAN STRAY"	SANDSTONE	0-80	☼
		MARSHALL	SANDSTONE sandy shale	100-400	
		COLDWATER	SHALE, sandstone, limestone	500-1100	
		SUNBURY	SHALE	0-140	
		BEREA-BEDFORD	SANDSTONE, SHALE	0-325	● ☼
		ELLSWORTH-ANTRIM	SHALE limestone	100-950	☼
DEVONIAN		TRAVERSE	LIMESTONE SHALE	100-800	● ☼
		BELL	SHALE, Limestone	0-80	
		ROGERS CITY-DUNDEE	LIMESTONE	0-475	● ☼
		DETROIT RIVER	DOLOMITE limestone salt anhydrite	150-1400	● ☼
		SYLVANIA	SANDSTONE, SANDY DOLOMITE	0-550	
		BOIS BLANC	DOLOMITE CHERTY DOLOMITE	0-1000	
SILURIAN	U	BASS ISLAND	DOLOMITE	0-570	
	U	SALINA	SALT, DOLOMITE Shale, anhydrite	50-4000	
	M, L	NIAGARA (Guelph-Lockport-Engadine) (Manistique-Burnt Bluff) (Cataract)	DOLOMITE, Limestone shale	150-800	● ☼
ORDOVICIAN		CINCINNATIAN (Richmond) (Maysville-Eden)	SHALE LIMESTONE	250-800	
		TRENTON-BLACK RIVER	LIMESTONE DOLOMITE	200-1000	● ☼
		ST. PETER	SANDSTONE	0-150	
OZARKIAN OR CANADIAN		PRAIRIE DU CHIEN	DOLOMITE, Shale	0-410	
		HERMANSVILLE	DOLOMITE, SANDY DOLOMITE, sandstone	15-500	
CAMBRIAN		LAKE SUPERIOR (Munising) (Jacobsville)	SANDSTONE	500-2000	
ALGONKIAN		KEWEENAW (Copper formations)	LAVA FLOWS, conglomerate, shale, sandstone	9800-35000	
		KILLARNEY GRANITE	GRANITE, GNEISS, diorite, syenite		
		HURONIAN (Iron formations)	SLATES, HEMATITE, SCHIST, QUARTZITE, GRANITE marble, dolomite	2000+	
ARCHEAN		LAURENTIAN	SCHIST, GNEISS, GRANITE		
		KEEWATIN	SCHIST, GREENSTONE, SLATE		

● OIL PAY

☼ GAS PAY

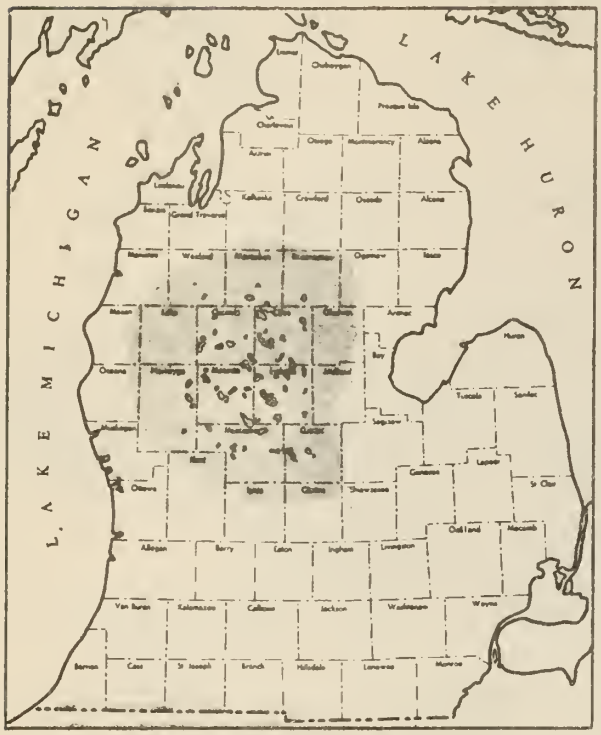
BASS ISLAND (H UNIT)	
G UNIT	
F UNIT (EVAPORITE)	
E UNIT	●
D UNIT (EVAPORITE)	
C UNIT	
B UNIT (EVAPORITE)	
A-2 DOLOMITE	☼
A-2 "LIME"	
A-2 (EVAPORITE)	
A-1 DOLOMITE	● ☼
A-1 (EVAPORITE)	

FIGURE 58.

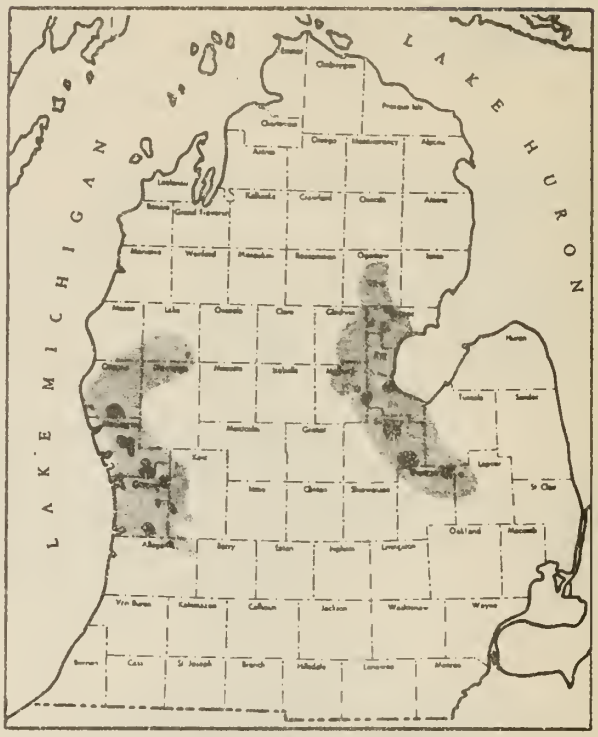
PRODUCING AREAS BY ROCK UNIT

OIL OR GAS POOL

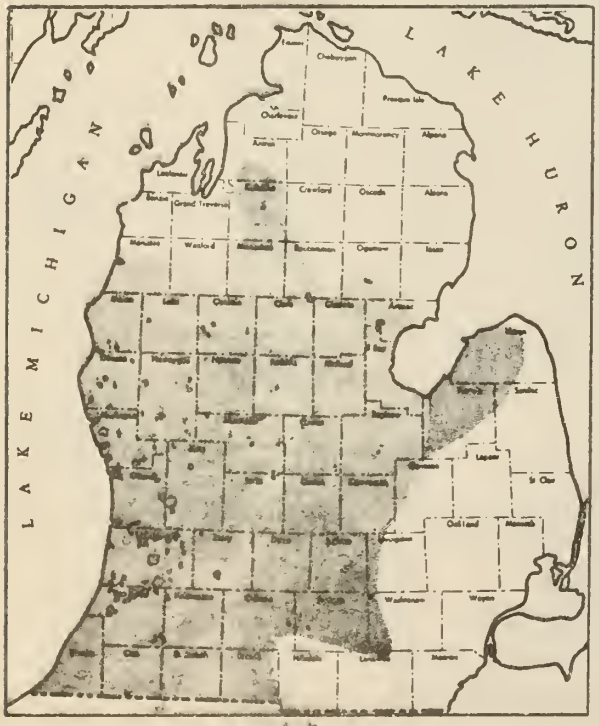
GENERAL PROVED AREA



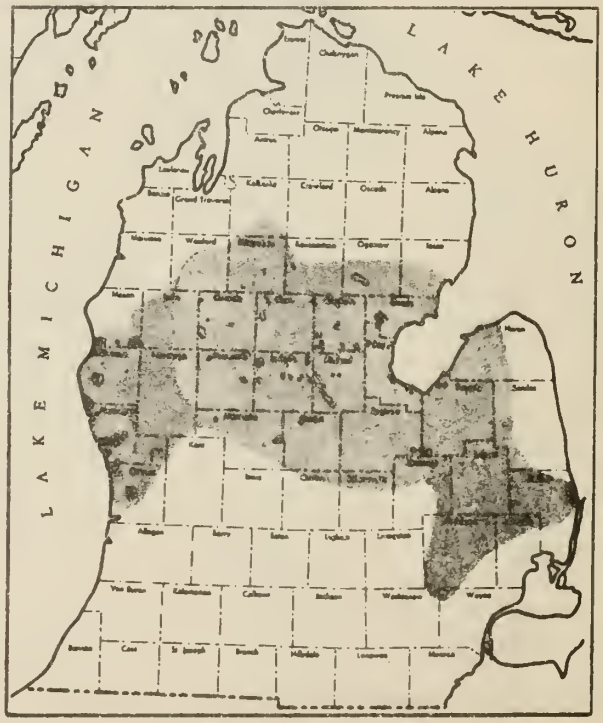
"MICHIGAN STRAY"



BEREA "FORMATION"



TRAVERSE GROUP



DUNDEE FORMATION

Figure 59.

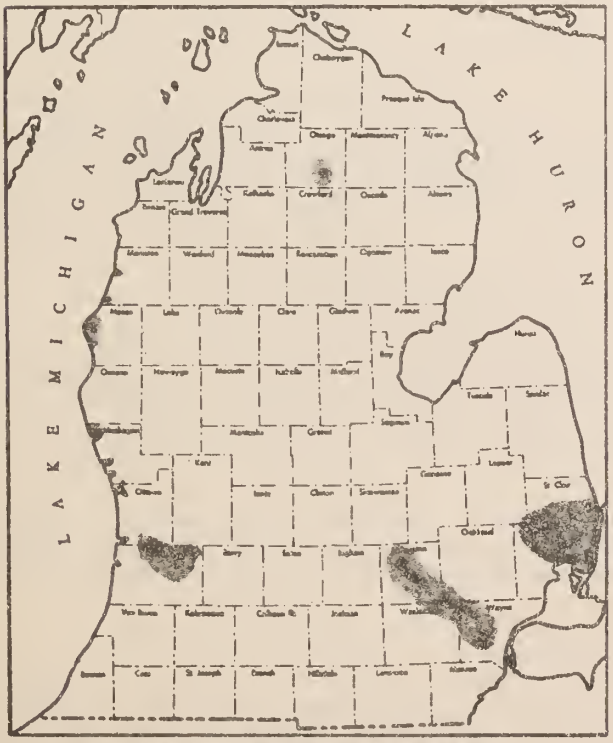
PRODUCING AREAS BY ROCK UNIT

OIL OR GAS POOL

GENERAL PROVED AREA

"REED CITY" ZONE

DETROIT RIVER GROUP



SALINA FORMATION & "NIAGARA"

TRENTON & BLACK RIVER FMS.

Figure 60.

Antrim (Mississippian)

The Antrim Shale is the source of gas in the overlying glacial drift in many areas where the Antrim forms the underlying bedrock unit. Small commercial gas production has been reported from the Antrim Shale in Otsego and St. Clair Counties.

The Antrim is a grey to brown, thinly bedded to fissle shale, interbedded with thin fossiliferous limestone beds near the base, and ranging from 150 to 450 feet in thickness. Accumulations of gas are believed to be largely anticlinal with fractures caused by crustal disturbances providing essential feeder channels for gas movement. The open flow capacity of the wells is very low, but experience indicates that wells can be expected to have very long producing lives. The formation is too tight to serve as an efficient gas storage formation and is considered unsuitable for this purpose although potential reserves are believed to be considerable.

Traverse Limestone (Devonian)

The Traverse Limestone reservoirs of Michigan had produced over 20% of the state's total oil production through 1959 with slightly over 2% of the total gas. The commercial Traverse gas production has been principally casinghead gas produced as a by-product of oil production. The Cannon Creek Gas Field in Kalkaska and Missaukee Counties and the Albion Gas Field in Calhoun County were the only Traverse gas fields produced commercially. Both proved uneconomic and were abandoned after brief producing histories. The Traverse Formation is considered adaptable for gas storage purposes by conversion of oil reservoirs. There is an excellent possibility for the recovery of considerable quantities of secondary oil production as a by-product of gas storage in Traverse pools lacking effective water drives. The high porosity and permeability of the Traverse oil pays suggests that wells would have high deliverability factors. Many of the Traverse reservoirs, while exhibiting good porosity and permeability, are of relatively small size and have been developed with a far higher well density than required for efficient gas storage operation. The reworking of many old producing and abandoned wells would be necessary to assure safe operating conditions and provide adequate protection for stored gas. Several Traverse oil pools underlie Stray-Marshall storage reservoirs and may eventually be converted to gas storage to serve as pilot projects to determine engineering problems involved and provide necessary performance and cost data for better evaluation of Traverse Formation gas storage prospects.

Rogers City-Dundee-Reed City Limestone (Devonian)

The Dundee and its associated pays have produced over 70% of the oil and 14% of the gas to January 1, 1960. Gas production has been essentially all casinghead gas associated with oil production. Among the larger Dundee reservoirs where casinghead gas plants were constructed to utilize casinghead gas are Porter-Jasper, Mt. Pleasant, Coldwater, Freeman-Redding, Reed City, and Sherman Pools. The pays are usually associated with dolomitization of the Dundee Limestone and secondary porosity development. The larger accumulations are anticlinal, but several important reservoirs with very prolific recoveries are classified as fracture reservoirs. Fracturing is believed to have played an important part in better pay development in many of the pools. Permeability traps associated with differential dolomitization are found in several pools. Several of these fields offer attractive prospects for conversion to gas storage reservoirs. The large initial oil potentials for the limited pay sections drilled suggest excellent deliverability, or open flow potentials would be obtained when converted to gas storage. Here again several of the larger reservoirs offer interesting secondary recovery prospects due to limited or ineffective water drives. The largest and most attractive reservoirs for gas storage purposes would include Porter, Reed City, Mt. Pleasant, Coldwater, and Freeman-Redding.

The Reed City and Coldwater Oil Pools underlie active Stray-Marshall storage reservoirs and appear to be excellent prospects for early and successful conversion to gas storage. Wider spacing and modern equipment and completion techniques should proportionately add to the value of recent and future Dundee reservoirs for storage use.

Detroit River (Devonian)

The Detroit River Formation was the third-ranking oil producing formation and fourth-ranking gas producing formation of Michigan on the basis of cumulative production as of January 1, 1960. The Detroit River pays are usually dolomites or dolomitic sandstones of low permeability occurring as a series of thin pay lenses separated by anhydrites and impermeable limestones. Wells have low initial producing rates

and relatively long producing lives. All reservoirs currently producing are associated with major anticlinal features of considerable areal extent. Flank porosity is frequently better developed than porosity over structurally higher areas. Gas caps have been present in many of the important reservoirs, but the major portion of the gas produced has been associated gas produced with oil. A number of the Detroit River oil fields have been unitized to permit fluid injection for secondary recovery operations and have modern casinghead gas plants and other valuable facilities adaptable to gas storage operations. The low permeability of the pays and high operating pressures required to assure satisfactory injection rates and deliverability may reduce the value of the reservoirs for gas storage use. Gas injection alone offers secondary oil reserves computed to be in excess of 15,000,000 barrels from the Detroit River fields to the end of 1959.

Salina-Niagaran (Silurian)

The basal Salina and Niagaran Dolomites are productive of oil and gas from widely separated areas in the Michigan Basin - Otsego, Mason, Ottawa, Allegan, Calhoun, Livingston, Washtenaw, Wayne, Macomb, and St. Clair Counties. The basal Salina and Niagaran Dolomites are currently the state's leading gas-producing formations, accounting for over 62% of the gas produced in Michigan during 1959 while showing only 11.5% of the state's cumulative gas production. The Salina-Niagaran contains all the principal gas-producing reservoirs in southeastern and southwestern Michigan. Porosity development was frequently associated with reef building during the period of deposition. Natural primary porosity has been altered by secondary dolomitization and fracturing processes. Porosity development may be intercrystalline and intergranular in the basal Salina dolomites while both intercrystalline and vugular porosity are present in the Niagaran. The reservoirs of southeast Michigan are principally in St. Clair and Macomb Counties. The reservoir rocks are in reef build-ups within the Guelph-Lockport Formations and the overlying A-1 dolomite unit in the basal Salina. Both oil and gas are produced from these so-called pinnacle reef pools, and large gas caps have been present in most of the pools developed to date.

Garland D. Ells of the Michigan Geological Survey ably covered the Silurian oil and gas developments in Michigan in a paper published in the June, 1960, Interstate Oil Compact Commission Committee Bulletin.

The Silurian oil and gas reservoirs are believed to be excellent prospects for future conversion to gas storage with the additional incentive of increased recovery of oil as a by-product of gas storage operations in many of the pools. The thick pay sections of the pinnacle reef pools offer excellent deliverability potentials for efficient gas storage development. Salina-Niagaran pools currently being developed for gas storage, or considered as excellent future prospects, are the Overisel and Salem Pools, of western Michigan; the Boyd, Peters, and Ira reef complex of St. Clair County; and the Howell Field in Livingston County. The potential oil and gas reserves of the Salina-Niagaran Formation are believed to be immense and offer great promise for future development throughout the Southern Peninsula of Michigan. A high percentage of the gas storage reservoirs of the future will be in Salina-Niagaran Formation pools in areas as yet unexplored.

Trenton-Black River (Ordovician)

The Trenton-Black River Formation during August of 1960 was responsible for 55% of the state's oil production principally from wells in the Albion-Scipio Trent Pools of southern Michigan. Core studies made on wells drilled in the Trenton-Black River of southern Michigan indicate that fracturing and minor faulting played an important part in reservoir development. Dolomitization and secondary porosity development appear to be best developed in zones subjected to greatest crustal deformation and structural adjustment. Prolific dolomite pay wells may be offset by wells in limestone with little or no porosity. A review of the Trenton-Black River Formation developments in Michigan was presented at the Interstate Oil Compact Commission meeting, June, 1960, in Detroit by Robert E. Ives of the Michigan Geological Survey and published in the June, 1960 Committee Bulletin of the Compact.

The thick gas cap section overlying the oil pays in the southern Michigan fields has suggested the possibility of future reservoir utilization for gas storage purposes. The strong evidence of complex fracturing points to considerable difficulty in defining reservoir geometry and limits of individual reservoirs. The low over-all porosity and permeability of the pay sections suggest that fracturing is essential to the development of commercial production in some areas. Excellent producing potentials have been reported and are an advantage in gas storage operations for offsetting peak loads. The difficulties of defining reservoir limits and of assuring protection of stored gas may handicap development of gas storage projects in

the Trenton-Black River Formation. The large Trenton-Black River gas reserves proven by developments of the last few years and the vast potentially productive areas remaining to be explored hold out excellent prospects for the future. The proximity to main gas line and markets, size of reservoirs, high deliverability of wells, and adaptability of reservoirs to gas storage purposes offer excellent prospects for future utilization of Trenton-Black River reservoirs for underground gas storage.

MINNESOTA

G. M. Schartz, Director
Minnesota Geological Survey

It seems unnecessary to go into detail regarding the stratigraphy of Minnesota, as it varies tremendously from place to place (figure 61). Most storage projects involve various formations ranging in age from Cambrian to younger beds. In Minnesota, rocks of Paleozoic age exist mainly in the southeastern quarter of the state. These are principally of Cambrian and Ordovician age but include the Cedar Valley Limestone of Devonian age.

The Cambrian rocks consist largely of sandstones, and nowhere are they sufficiently impervious to provide a seal. The Ordovician rocks consist of dolomite, limestone, sandstone, and a limited amount of shale. Unfortunately for storage possibilities, the shale is interbedded with limestone and nowhere, to date, has a sufficient thickness of pure shale been found to provide conditions for gas storage. The limestones and dolomites have been investigated and drilled to some extent for LPG storage, but the leached and vuggy condition has been discouraging.

Mesozoic rocks are represented mainly by remnants of both marine and lacustrine Cretaceous sediments, but these are nowhere thick enough and continuous enough to be of interest and have not been considered worthy of exploration.

Attention lately has been centered on Precambrian rocks, especially granite. The Precambrian also includes a variety of igneous and metamorphic rocks such as granite gneiss, gabbro, basalt, rhyolite, many many varieties of schist, quartz, and iron formation. Several of these types are probably suitable for LPG storage. The rocks occur at relatively shallow depths (0-500 feet) through large areas of western, central, and northeastern Minnesota. Aside from the universal problem of cost, the problems in Minnesota have to do with location of pipelines with respect to the easily accessible granite areas. The big area of gas consumption is the Minneapolis-St. Paul Metropolitan Area, and unfortunately this is a region of Paleozoic rocks with the unfavorable conditions noted above. At the moment an L. P. pipeline is being built to the metropolitan area entering the state from the southwest. This is somewhat east of readily accessible granite, but it is possible that a suitable site may be found within reach of a branch line. It is understood that active work is proceeding on the problem.

The gas pipeline now entering the state from Canada will traverse the width of northern Minnesota from near the northwest corner to Duluth. This opens up new possibilities for storage in granite, but very thick glacial drift at places is a problem, particularly in exploration. It is understood that exploration for a site is underway.

Gas storage in Minnesota is highly desirable because of the extremes of heat and cold which cause unusually severe fluctuations in the use of gas for heating. For this reason the possibility of storing natural gas from the pipelines (figure 62) supplying the state and LP gas has been investigated for at least ten years. To date, however, a successful situation for storing either type has not been located, and there is no storage at present although investigations have been active during the last year or more.

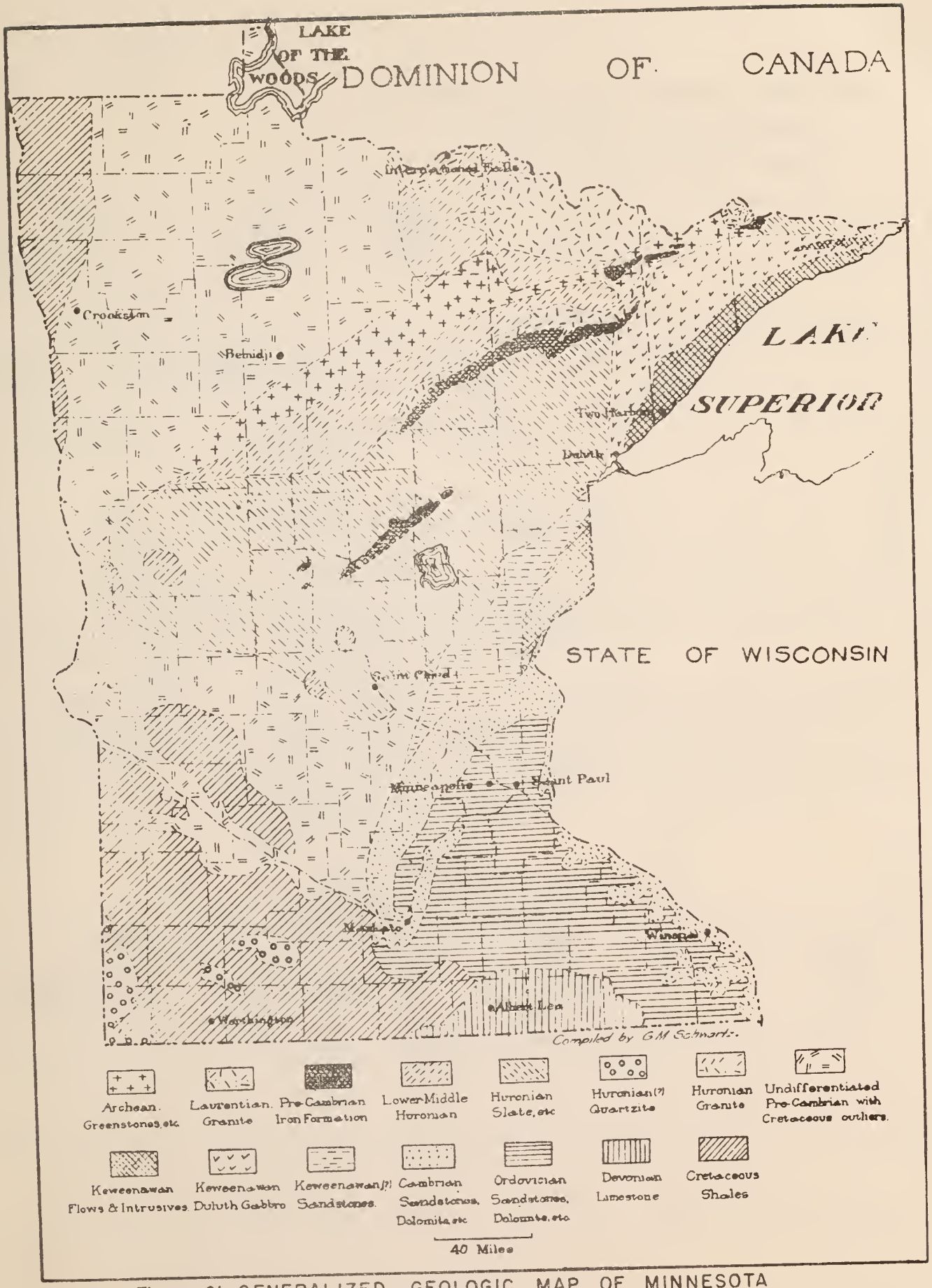


Figure 61. GENERALIZED GEOLOGIC MAP OF MINNESOTA

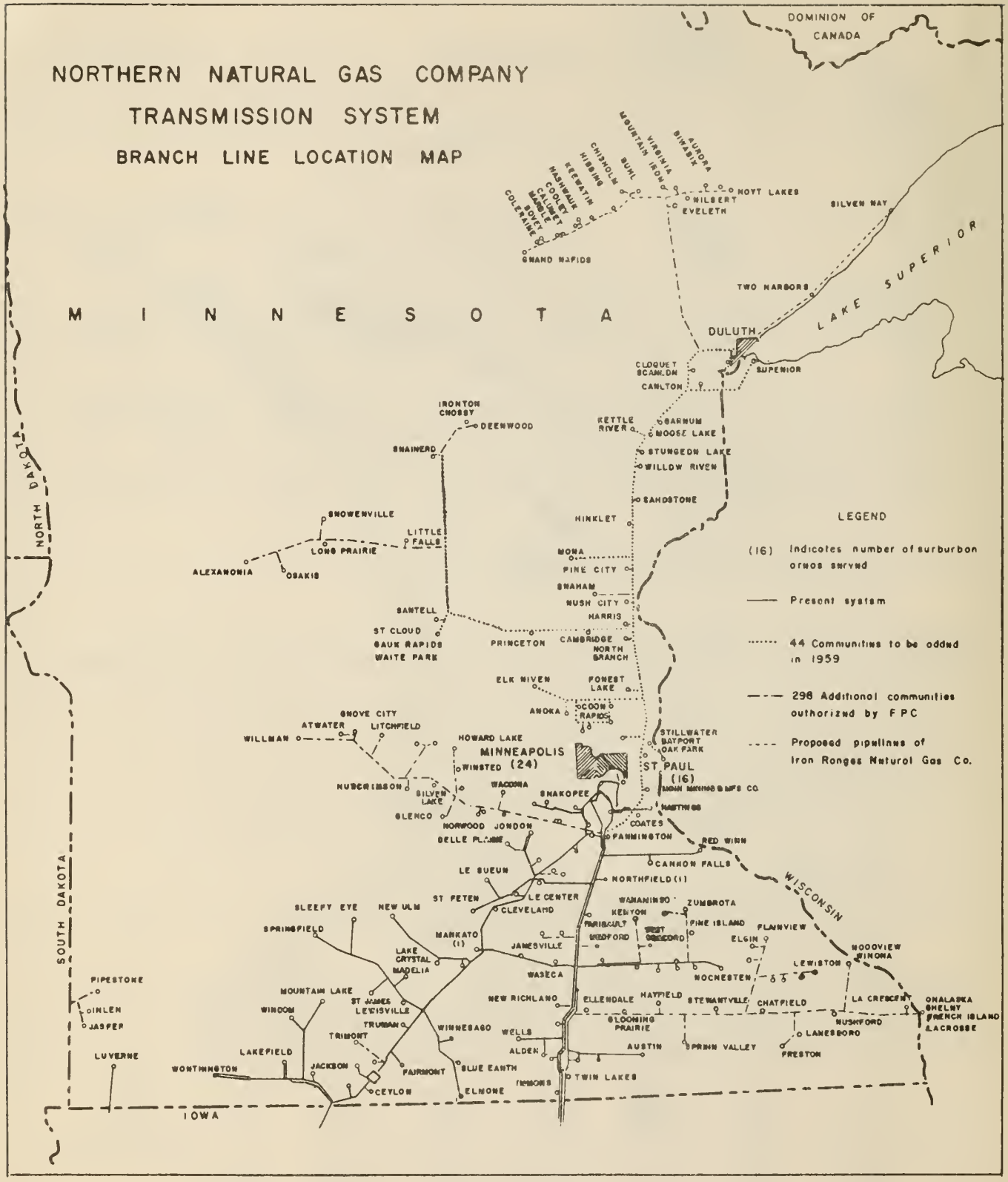

NORTHERN NATURAL GAS COMPANY
TRANSMISSION SYSTEM
BRANCH LINE LOCATION MAP
DOMINION OF CANADA
M I N N E S O T A
NORTH DAKOTA
SOUTH DAKOTA
IOWA
WISCONSIN
LAKE SUPERIOR
DULUTH
SUPERIOR
MINNEAPOLIS (24)
ST PAUL (16)
LEGEND
(16) Indicates number of surburban areas served
Present system
44 Communities to be added in 1959
298 Additional communities authorized by FPC
Proposed pipelines of Iron Ranges Natural Gas Co.

Figure 62.

MISSISSIPPI

James F. Borthwick, Jr., Chief Engineer
State Oil and Gas Board

The State of Mississippi currently has only two areas for the underground storage of natural gas.

The depleted Amory Gas Field located in Monroe County is used by Mississippi Valley Gas Company for storage during summer months to supply its nearby markets. Storage was commenced in the spring of 1953 by Mississippi Valley Gas Company. Three wells are used for injection purposes at a depth of 2,300 feet in the Hartselle Sandstone of the Mississippian. The total storage capacity is one million Mcf with the injection pressure 750 pounds.

A depleted segment of the Jackson Gas Field located in Rankin County is maintained by United Gas Pipe Line Company for a storage area. Storage was commenced in 1956. Nine wells are used for injection purposes at a depth of 2,100 feet in the Selma Gas Rock sand of the Upper Cretaceous. The total storage capacity is approximately 233,000 Mcf per month with an injection pressure of 975 pounds.

Mississippi does not have any statutes which specifically provide eminent domain proceedings for the storage of natural gas.

MISSOURI

Kenneth H. Anderson, Subsurface Geologist
Missouri Geological Survey

The storage of natural gas is becoming increasingly important in the state. Heavy winter industrial and domestic demands bring on problems of seasonal differentials, and adequate storage facilities above-ground are often undesirable or unfeasible. Underground storage of gas during times of summer low consumption is an ideal solution to the problem. The two areas of greatest population density, Kansas City and St. Louis, are underlain by strata geologically suited to storage of gas.

The Kansas City area is better situated than St. Louis in that near Kansas City and in surrounding counties practically unlimited possibilities exist for storage in the cyclically deposited Pennsylvanian beds. These beds contain stratigraphic traps from which gas and oil have been produced in the past and consequently offer perfect locations for injection and storage of gas at the present. Lenticular sandstones capped with dense limestones and shales are attractive for storage in the Cherokee of Lower Pennsylvanian age, and other stratigraphically higher formations offer similar possibilities. Many of these possibilities lie within the conditions set up in Missouri statutes governing gas storage as cited at the end of this discussion.

Pennsylvanian Possibilities

The Pennsylvanian beds in western, northwestern, and northern Missouri offer the greatest opportunities for gas storage in the state. Depleted gas and oil fields in the Pennsylvanian can readily be adapted to the storage of gas. Many known and unknown stratigraphic conditions offer possibilities as reservoirs to contain the gas. In general, the old pools are in lenticular, porous, and permeable sands with shale or impervious limes and shales sealing off the productive zones. Many of the old localities lie below the statutory 500-foot minimum depth limit. Many areas, however, are still producing very small amounts of gas used locally in homes and would not qualify for storage areas under the Missouri statutes. Pennsylvanian rocks of Missouri usually contain highly mineralized ground waters unusable for livestock and domestic purposes; hence, properly designed and operated storage would not contaminate potable water horizons.

Within the Pennsylvanian, we know of only one commercial gas-producing area at present, the Turney Gas Pool in Clinton County. There may be some individual wells and small fields which are producing, about which we have no knowledge. For example, there are over 400 wells drilled in the Blue Springs Gas Field Area in Jackson County between 1928 and 1933. It is not known how many, if any, are still producing.

Most of the gas and oil in those counties of western and northwestern Missouri which have Pennsylvanian rocks has come from the Cherokee or more specifically the Krebs subgroup and Cabaniss (Lagonda Formation)sands. Other fields have produced from the Marmaton and Pleasanton groups above the Cherokee.

Specific Areas and Pertinent Data (extracted from 57th Biennial Report of the State Geologist)

Blue Springs Gas Field, Jackson County, Missouri. - The first well was completed in 1928. The average closure on 14 anticlinal and nose features within the field is 30 feet. Production is from Lagonda sand (Upper Cherokee age).

The Lagonda ("Squirrel") sand, as found at Blue Springs Field, is usually approximately 50 feet below the top of the Cherokee. It is coarse grained, porous, buff to brown in color, and broken by argillaceous or calcareous layers. It is an average of 40 feet thick but may be absent locally.

Locally a channel deposit was drilled in the Blue Springs Field. This deposit, usually considered as correlative with the Warrensburg channel fill, is developed on the unconformity between the Pleasanton and Marmaton groups. The channel deposit usually produced gas but rarely produced oil in commercial quantities.

It is entirely possible that within this area only the Cabaniss sands within the Cherokee could be used, since thicknesses for the overlying section above Cherokee indicate less than 450 feet available section and less than 500 feet required by statute. However, the significance of the shoestring channel deposits in deeper occurrence is readily seen.

The seals for any gas storage in the Cherokee would be the numerous shales, dense argillaceous limes, coals, and underclays, above and within the Cherokee. The top of the Cherokee is at an average of 330 feet below the surface and is at least 350 feet thick at this point (Bartle et al, 1933).

Other fields which have produced from Lagonda or Cabaniss sands and higher formations are as follows:

County	Pool	Producing Sand	Depth
Cass	West Line	Lagonda ("Squirrel")	450'
Cass	Beeghly & Knight	Lagonda ("Squirrel")	500'
Cass	Belton	Lagonda ("Squirrel")	500'
Cass	Knuche	Lagonda ("Squirrel")	500'
Jackson	Grandview	Lagonda ("Squirrel")	600'
Jackson	Martin City	Lagonda ("Squirrel")	550'
Jackson	E. Kansas City	Lagonda & "Bartlesville"	500'
Jackson	Kansas City	Bartlesville	500'
Clay	Avondale	Lagonda	475'
Clay	Liberty	Anna	500'
Clay	Paradise	Walter Johnson	600'
Platte	Parkville	Walter Johnson	600'
Clinton	Plattsburg	Anna	550'

As was stated previously, there are many small, very shallow pools which have produced oil and gas in the past, while the pools listed are only those which produced from near or below the 500' below the surface limits. Many produced from above that limit and would not be potential storage areas; however, those pools which lie below or near the 500' limit plus other unknown sand lenses constitute a practically unlimited source for speculation within that part of the state which has Pennsylvanian rocks.

Pre-Pennsylvanian Possibilities

Within the pre-Pennsylvanian the possible storage areas are less numerous, deeper, and are usually created by structures. Approximately three-fourths of the state can be eliminated because of statutory prohibition of storage in areas of potable water occurrence.

Most of the state which is not covered by Pleistocene deposits or Pennsylvanian rocks contains ground water which meets the accepted standards of potability and is therefore prohibited as to the injection of any contaminating liquid or gas. With a few exceptions, this leaves an area roughly confined to north of the Missouri River and west of 94° west longitude.

In general, the basal Mississippian Kinderhook shales are the first reliable cap rock beneath the Pennsylvanian. The entire Mississippian section above the Kinderhookian in northern Missouri is predominantly limestone and chert and contains no capping sediments which would confine gas injected into the coarsely crystalline limes. In areas which have Mississippian sandstone, the sandstones are too near the surface and have no capping rock sufficiently dense to confine gas. Kinderhook shales are found associated with structures which offer large-scale possibilities in northeastern and north-central Missouri.

The Kinderhook would necessarily have to be in contact with some suitable storage rock below the unconformity which puts many different formations in contact with Kinderhook throughout the occurrence area.

Although the Kinderhook is an excellent cap rock where it is a shale, it varies in lithology in different parts of the state. It varies as follows: a dense lithographic limestone (Louisiana) in northeastern Missouri; an argillaceous and sandy dolomitic lime (Chouteau and Sedalia) in central Missouri; shales and sands (Grassy Creek) in northeastern Missouri; the Northview Shale and Sedalia in southwestern Missouri; and crystalline limestone of the Compton in southwestern and western Missouri. Efficient storage would depend on its impervious condition over a structure.

In Knox County of northeastern Missouri, the Kinderhook is a dense lithographic limestone, the underlying Devonian is a dense cherty limestone, and neither the Kinderhook nor Devonian offers much porosity for gas injection. Underlying the Devonian is the Ordovician Kimmswick ("Trenton") which in the Knox County area is a cherty dolomite, whereas, in areas farther southeast it is a porous, coarsely crystalline limestone and suited for storage if sufficiently permeable. In the Knox County area, the best horizon for storage would be the Ordovician St. Peter Sandstone occurring at ±990 feet below the surface. The St. Peter, which is ±45 feet thick, is a well sorted, rounded sand having excellent porosity. Below the St. Peter the next possible storage horizon is the Ordovician Roubidoux Formation which in many areas is very sandy, cherty, and oolitic. Where sufficient porosity and structure occur, the Roubidoux could be used. At the base of the Ordovician and above the unconformable Cambrian surface, the Gunter Sandstone occurs. This formation varies widely in thickness from 0 to more than 100 feet and is composed of poorly sorted sand and some shale. Where sufficient structure is present, the Gunter might be used for storage with overlying dense Gasconade dolomites forming an impervious seal.

The Cambrian Lamotte Formation, at the base of the sedimentaries and overlying the Precambrian, forms a suitable gas reservoir in many areas. The Lamotte is composed of coarse, poorly sorted sand, very arkosic, with some shales. Occurring at the base of the section, it is often quite deep as at the Knox County area where it is ±1,700 feet to the top of the Lamotte. Overlying the Lamotte is the Bonneterre dolomite which in most cases would form an adequate seal. The Lamotte increases in thickness from south to north. In north central Missouri the Lamotte is ±100 feet thick, whereas in northeast Missouri it has increased to ±450 feet. The Precambrian surface is very irregular, and the Lamotte sandstone presents excellent storage possibilities in many cases.

Specific Areas

Pre-Pennsylvanian

No. 1. (Index map figure 63). Northern St. Louis County. - This is the only project in Missouri now actively engaged in use of gas from subsurface storage. Laclede Gas Company of St. Louis is the owner and operator.

Gas is stored in the St. Peter Formation with overlying Decorah, Plattin, and Joachim forming the impervious seal. In most cases, where rocks have a permeability of 0.01 millidarcies, it is considered impervious to gas. Where the sealing rocks are water-saturated, the impermeability is even greater. Closure in this project is in the vicinity of 200 feet with the St. Peter ranging in thickness from 93 to 150 feet and generally lying more than 1,400 feet below the surface.

Lithologies of the overlying sealing rocks are: Decorah - limestone with chert nodules and bands of brown and green shale, average thickness 25 feet; Plattin - fine-grained limestone with small amounts of chert, average thickness 160 feet; Joachim - massive dolomite, argillaceous and shaly with some sand near base, average thickness 130 feet; St. Peter - white sandstone.

No. 2. Western St. Charles County. - This area is shown in the zone of fresh water on the map; however, conditions in the St. Peter Sandstone are rather unpredictable, and salt water could conceivably

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MISSOURI

TOPOGRAPHIC DIVISION
CENTRAL REGION
ROLLA, MISSOURI

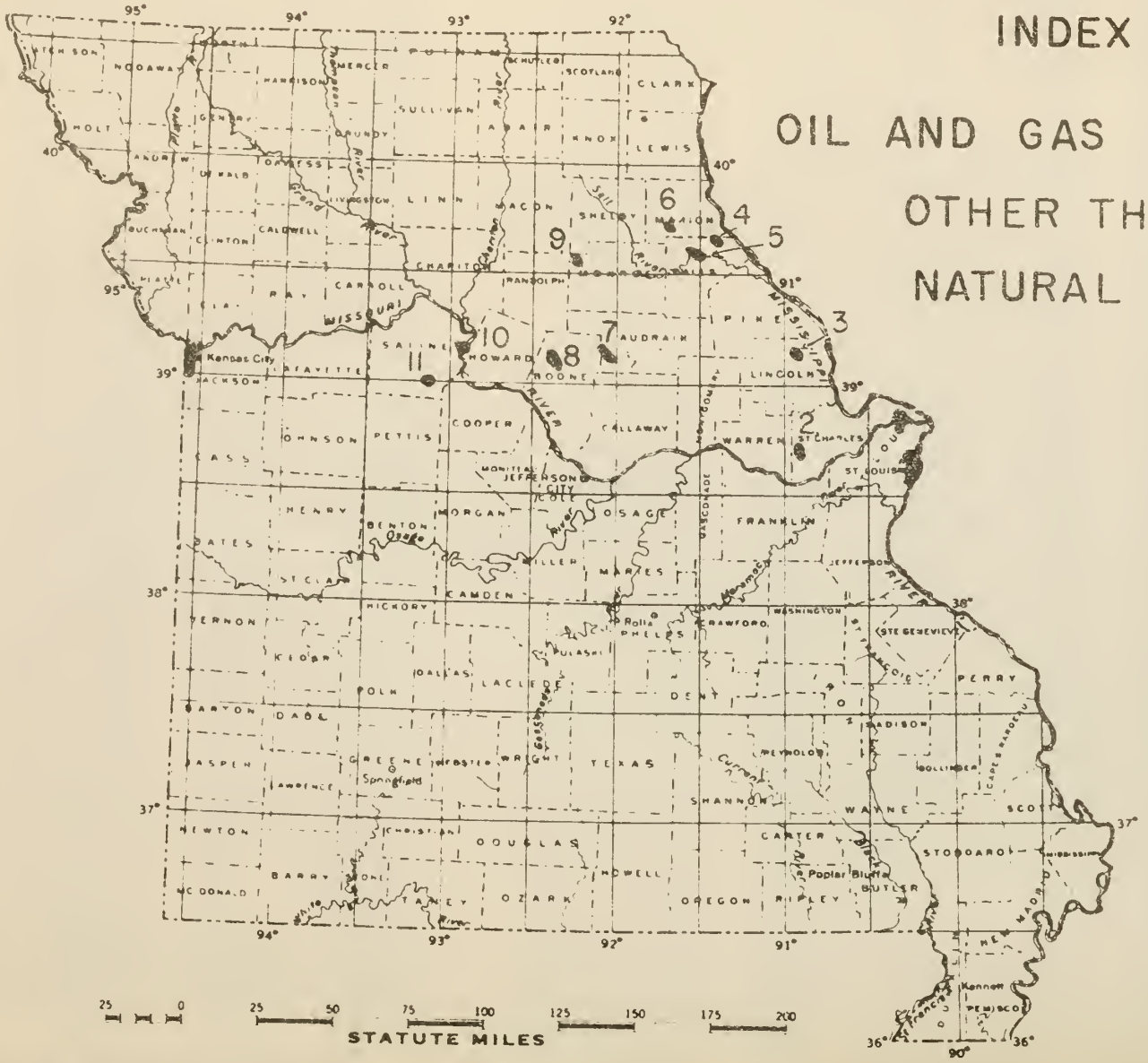


Figure 63.

be found at or below the St. Peter. Further work would have to be done on this area since information is scant, and the St. Peter is indicated at less than 400 feet from the surface. Deeper formations such as the Roubidoux, Gunter, and Lamotte would be objectives. Information indicates as much as 300 feet of closure on the St. Peter. Whether this closure exists at depth is not known. Faulting may also enter into the picture. The St. Peter crops out less than 6 miles to the south and southwest, but a steeper dip is indicated to the north and northwest. Subsurface data show as much as one degree at the north and east sides of the structure with little control close enough to define other dips. Low dips on the St. Peter tend to lessen the attractiveness of this particular area. Unless greater structural deformity exists at depth, the area is not of great interest.

No. 3. North-Central Lincoln County. - Information indicates that several high areas may exist in Township 50 and 51 North, Range 1 West. Not enough closely spaced data are available to show these features well or indicate closure. However, in Sections 1 and 10 of Township 50 North, Range 1 West, and Sections 17 and 23 of Township 51 North, and Range 1 West, indications are that the St. Peter Formation is less than 100 feet from the surface. The St. Peter crops out in three small areas very close to these locations and is therefore unusable for storage. Faulting is also present and may contribute to rendering the area less interesting. In this area where St. Peter is at the surface, the Roubidoux sand should be at ∠500 feet below the lower St. Peter contact.

To the south of this general area, the Roubidoux occurs at 1,300 feet and is 135 feet thick with 75 feet being more than 50% sand. Overlying dense Jefferson City and Cotter Dolomites should seal in any injected gas with Roubidoux ground water forming a good lower seal to pump against. Below the Roubidoux the next horizon would be Gunter at the base of the Ordovician occurring at about 700 to 800 feet depth. This formation is thin and not well known in this area. The Lamotte occurs at 2,400 feet at a point 6 miles north of these areas and should be in the vicinity of 1,500 to 1,700 feet in depth within the area. The Lamotte would be an excellent storage horizon with thick overlying Davis Shales and Potosi-Eminence Dolomites which might help form a seal although in many areas Potosi-Eminence is quite porous. Provided faulting does not break closure, several storage locations might be found in this general area.

No. 4. Northeastern Ralls County. - Little information is available on deep structure in areas of northeastern Missouri. This particular area of interest was picked from map observation of the Devonian showing through the Mississippian. This is also the case with areas 5 and 6. All three areas are on the trend of the Lincoln Anticline. About 10 miles south of area 4, it is known that the St. Peter is very near the surface in Township 55 North, Range 4 West, Section 28, and it is ∠600 feet below the surface in Township 55 North, Range 5 West, Section 34. In the Section 34 area the St. Peter reaches an abnormal thickness of over 200 feet. However, in these two areas, Section 34 where the St. Peter is low the Precambrian is found at ∠1,700 feet with all the Cambrian missing below the middle Derby, and in the Section 34 area where St. Peter is high the Precambrian is below 2,200 feet. With all the Cambrian present this makes for a peculiar situation with the St. Peter high being located over a Precambrian low and the St. Peter low over a Precambrian high. It is not known to what extent this situation exists, or if the Precambrian is a ridge or a knob of small areal extent. The area is high, and additional work might prove excellent storage conditions in the Roubidoux or Lamotte Formations.

No. 7. Western Audrain County. - The St. Peter is too shallow to be of interest. The Roubidoux might not be porous enough here to provide space for gas since it is less sandy than in other areas. It should be found at ∠900 feet in depth and the Gunter at ∠1,200 feet. The Gunter is sandy but only 15 to 30 feet thick. The Lamotte should be over 100 feet thick and at a depth of ∠2,100 feet. On the top of the St. Peter, some 45 to 70 feet of closure is indicated. Faulting is not known to be present; however, it is present in area 8 to the west and is possible in area 7 also. Ground water in this area is generally potable; however, there is a lack of subsurface information due to a paucity of deep holes.

No. 8. Northern Boone County. - This area is at present under study for possible development, and information of a specific nature is not available. However, subsurface data show no St. Peter present over the structure with Roubidoux occurring at ∠700 feet with comparatively little sand. The Gunter is at ∠1,000 feet and 20 feet thick. The objective in this area would be the Lamotte sand occurring at ∠1,875 feet and over 100 feet thick. This sand is fine to coarse and poorly consolidated. The overlying Davis shales and silts might not be a good seal, but the section above the Davis is composed of more than 1,400 feet of dense dolomite which should prevent gas escape. Faulting might break closure in this area and may make it unfeasible for gas storage.

No. 9. Northwest Monroe County. - This area is in the part of the state where potable ground water is not found below the drift; consequently there is a great lack of deep wells for information. However, if the area is structurally high the St. Peter may be less than the required 500 feet from the surface since it is at 600 feet in a well at Moberly, Missouri, 12 miles to the southwest. The St. Peter is 75 feet thick at Moberly with Devonian sandstone and dense limestone above. At Moberly the Roubidoux occurs at 1,150 feet and is very sandy with dense cherty dolomite overlying the 100 feet thick sandstone zone. Very sandy Gunter was found at 1,415 feet. The other objective in this area would be the Lamotte, probably occurring below 1,800 feet and of unknown thickness.

No. 10. Eastern Saline County. - This area is a known structural high. Both Devonian and Upper Ordovician rocks crop out in this area surrounded by Mississippian rocks. Three miles northwest of this area the St. Peter is less than 300 feet from the surface and consequently would be much too shallow within the structure area to be used for storage. The deeper Roubidoux, Gunter, and Lamotte would, therefore, be objectives. At Marshall, Missouri, 12 miles to the west of the structure, the Roubidoux is below 750 feet and is very cherty with an average of 25 percent sand. The Roubidoux is 125 feet thick. The Gunter is at 1,100 feet and is 40 feet thick with 20 feet of it being more than 50% sand. The Lamotte is estimated at 1,875 feet and would be of unknown thickness in this area. Within the structure area these depths would be different depending on the amount of structure present. Thickness might also be different over the structure.

No. 11. - Twelve miles south-southeast of Marshall, Missouri, in Saline County, an area is similar to No. 10, and lack of deep subsurface data makes a description difficult. The St. Peter is absent in this area with Ordovician Cotter Formation present at ±150 feet. This area may have as much as 100 feet of closure on the top of the Cotter Formation. Roubidoux should be found at ±500 feet and Gunter at ±825 feet. The Lamotte might be as deep as 1,700 feet and of unknown thickness.

In all the 11 areas mentioned, drilling for subsurface data and resultant cross-section construction are needed to determine whether sufficient closure is present. Specific zones of interest would have to be analyzed to determine whether proper reservoir conditions are present to allow gas to be economically injected, retained, and reproduced without loss, danger to property owners, or possibly of reservoir failure.

Missouri Statutes on Gas Storage

From Missouri revised statutes, Cumulative Supplement 1955, Chapter 393.

393.460. Strata and formations not subject to condemnation. - No stratum or formation lying less than 500 feet below the surface, and no stratum or formation containing potable water conforming to the mineral content standards of the United States Public Health Service, and no stratum or formation containing natural gas or oil producible through primary production methods in commercially paying quantities or producing domestic supplies of natural gas or oil, and no stratum or formation containing coal or the ores of lead, zinc, iron, copper, barium, or any precious metal, producible on a commercially paying basis, shall be subject to be condemned for utilization for the underground storage of gas therein. (L1953 p. 51385).

According to section 393.430 a gas storage company may exercise the rights of eminent domain, subject to limitations and provisions of sections 393.410 to 393.510 of Missouri Revised Statutes. To acquire by condemnation and or interests in land, necessary or convenient to its operations as a gas storage company including such operations as drilling of test holes or wells necessary or convenient to determine the suitability of a geological stratum or strata, formation or formations for the underground storage of gas - the laying, operation, and maintenance of necessary pipe lines and operating equipment and installations necessary for convenient operation of the gas storage operation under chapter 393 of Missouri Revised Statutes, Sections 393.410 to 393.510 apply to powers of gas storage companies.

Other sections deal with definitions, acquisition rights under publicly-owned land, approval of Public Service Commission, buildings, rights of owner of land in condemned strata, personal property limitations, etc.

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MONTANA
Southern District Field and Technical Office
The Oil and Gas Conservation Commission

General Remarks

Natural gas was discovered in commercial quantities in Montana with the development of Baker-Glendive Gas Field. This Cedar Creek Anticline Field was discovered in 1912. Added impetus was gained in gas production from Kevin-Sunburst-Shelby in 1922 and the Cut Bank area in 1926. Most of the gas pipelining was done in the late 20's and early 30's. Natural gas, the ideal industrial and domestic fuel, has long been in demand in the state. The domestic winter peak load is five times greater than the summer load because of the temperature differential of the two seasons. The industrial load, although not seasonal, also varies. Because of the above, Montana has long been interested in gas storage

The following is a summary of a report by the Oil and Gas Conservation Commission prepared in 1954:

"The Oil and Gas Conservation Commission has made a technical study of the proposition and requirements of underground storage of natural gas; it has examined the gas industry within the State; it has held a public hearing for the purpose of obtaining information, views and opinions relating to our problem of underground storage, and condemnation for such purposes; and it has examined in detail the laws of the other states having similar problems. It has been concluded by the Commission that:

"(1) The underground storage of natural gas is in the public interest because it will promote the conservation of gas, make it more readily available to the domestic, commercial and industrial consumers, and permit the building of natural gas reserves and orderly withdrawal thereof in periods of peak demand.

"(2) Montana does not have a surplus of gas capacity or reserves to meet consumer needs and is dependent upon importation on the order of approximately 30% of its present consumption. Industry should be encouraged to develop a source of supply for Montana both by importation contracts and further development within the State.

"(3) Underground storage in 'barren reservoirs' is two to three times as costly as in 'depleted reservoirs'; it is considerably more hazardous mechanically, and is essentially in the experimental stage.

"(4) Underground storage should be encouraged in depleted, and otherwise useless, gas and oil reservoirs when such can be accomplished by mutual agreement between the utility and mineral owner.

"(5) Legislation should provide for condemnation under the rights of eminent domain of depleted gas reservoirs when such is found to be in the public interest; however, condemnation should take place only after it has been shown that voluntary methods of acquisition are ineffective.

"(6) Legislation pertaining to condemnation of depleted oil reservoirs is not in order at this time due to a complexity of problems and the fact that there are no such depleted situations existing in the State."

Unfortunately, in Montana, as in other states, geography and geology are not always compatible insofar as underground gas storage projects are concerned.

Gas Production and Storage in Montana

Montana Gas Fields

Montana's gas is produced from fields on the eastern margin of the state westward to the Continental Divide. To date no gas has been found across the Divide.

Figure 64 shows the distribution of the producing and non-producing fields in the state, and table 25 gives a complete breakdown of the individual fields.

Gas Pipelines in Montana

Figure 64 gives the location, size, and operator for all gas lines within the state.

Cumulative Injection

Figure 65 gives a summary of the growth of underground storage in the state for the past ten years.

Table 25 - Gas Production Data for Montana

Field	County	Producing Formation	1959 Production Mcf	1960 Production Mcf
Bears Den	Liberty	Kootenai	61,299	72,429
Big Coulee	Golden Valley	Lakota-Morrison	851,730	889,161
Bowdoin	Phillips & Valley	Colorado	3,618,401	5,075,532
Bowes	Blaine	Eagle	897,011	1,432,364
Box Elder	Blaine & Hill	Eagle	0	67,852
Cabin Creek	Fallon	*Siluro-Ordovician	970,766	1,094,251
Cedar Creek	Fallon & Wibaux	Judith River & Eagle	5,058,820	4,572,964
Clarks Fork	Carbon	Lakota & Dakota	821,135	640,677
Cut Bank & Reagan	Glacier & Toole	Kootenai	10,167,463	11,231,488
Devon	Toole	Colorado	87,216	97,801
Dry Creek	Carbon	Cretaceous	1,488,715	1,700,909
Elk Basin	Carbon	*Tensleep	841,540	762,145
Flat Coulee	Liberty	Kootenai	232,192	100,210
Golden Dome	Carbon	Eagle	33,439	13,534
Grandview	Liberty	Greenhorn	278,904	361,794
Hardin	Big Horn	Frontier	41,819	45,289
Keith Block	Liberty	Sawtooth-Madison	1,249,426	1,391,779
Kevin-Sunburst	Toole	Kootenai	1,034,964	1,169,557
Pine	Dawson, Prairie Fallon, Wibaux	*Siluro-Ordovician	933,266	1,022,681
Plevna	Fallon	Judith River	211,657	201,676
Utopia	Liberty	Sawtooth-Ellis	1,231,099	543,487
Whitlash	Liberty	Colorado	887,554	1,180,833
Miscellaneous			778,844	1,017,537
Total all fields			31,740,260	34,685,950

* Gas produced with oil

Montana Shut-in Gas Fields

Shut-in gas fields are as follows: Blackleaf Canyon, Gildford, Gypsy Basin, Havre, Kremlin, Liscom Creek, North Lake Basin, Pumpkin Creek, Rapelje, Rudyard, and Sherard.

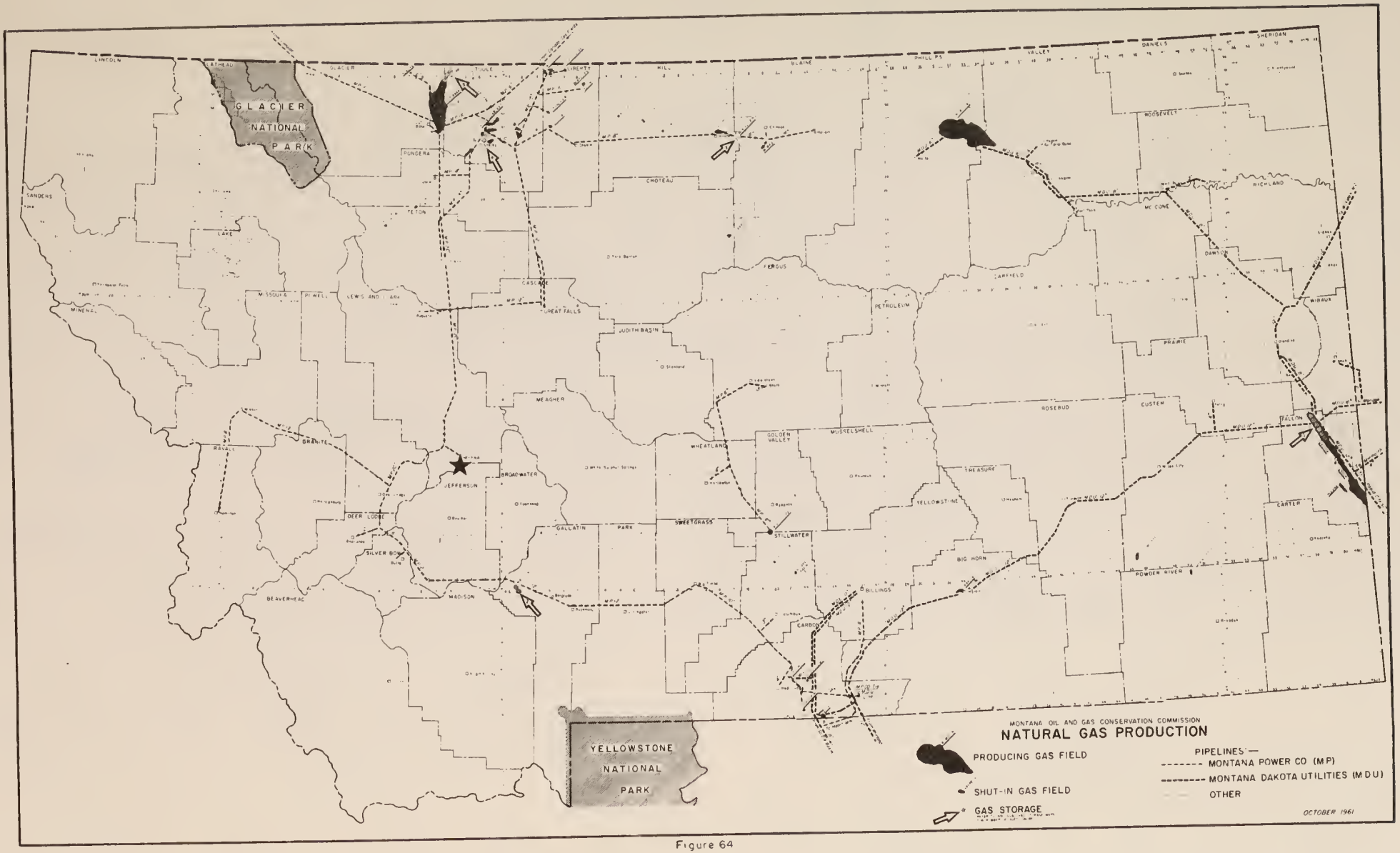
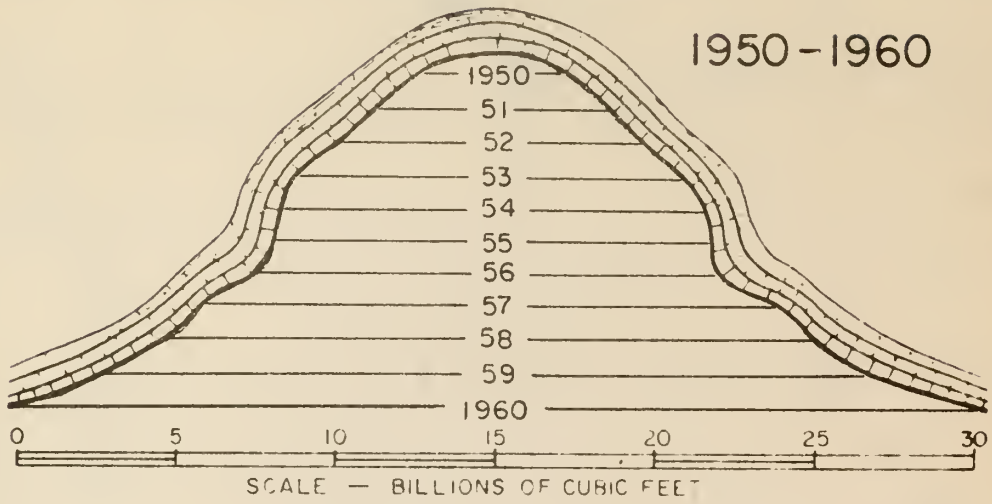

MONTANA OIL AND GAS CONSERVATION COMMISSION
NATURAL GAS PRODUCTION
PRODUCING GAS FIELD
SHUT-IN GAS FIELD
GAS STORAGE
PIPELINES —
MONTANA POWER CO (MP)
MONTANA DAKOTA UTILITIES (MDU)
OTHER
OCTOBER 1961
GLACIER NATIONAL PARK
YELLOWSTONE NATIONAL PARK
LINCOLN
LATHEAD
GLACIER
TOOLE
LIBERTY
HILL
BLAINE
PHILLIPS
VALLEY
DANIELS
SHERIDAN
ROOSEVELT
RICHLAND
MC CONE
DAWSON
WIBAUX
PRAIRIE
FALLON
CUSTER
ROSEBUD
CARTER
POWDER RIVER
CARFIELD
PETROLEUM
FERGUS
CHOTEAU
PONDERA
TETON
CASCADE
GREAT FALLS
JUDITH BASIN
MEAGHER
WHEATLAND
GOLDEN VALLEY
MUSSELSHELL
TREASURE
YELLOWSTONE
BIG HORN
BILLINGS
CARBON
STILLWATER
SWEETGRASS
GALLATIN
PARK
BROADWATER
JEFFERSON
MADISON
BEAVERHEAD
SILVER BOW
DEER LODGE
GRANITE
RAVALLI
MINERAL
MISSOULA
POWELL
LEWIS AND CLARK
LAKE
SANDERS

Figure 64

NET GAIN IN GAS STORAGE —



M.C.F.

YEAR	TOTAL	CEDAR CREEK	MADISON	SHELBY	BOX ELDER
1950	4,040,935	4,040,935			
1951	7,033,074	7,033,074			
1952	9,067,457	9,032,719	34,738		
1953	12,037,743	11,390,136	647,607		
1954	13,171,054	11,936,844	1,234,210		
1955	13,239,062	11,742,513	1,496,549		
1956	13,669,015	11,870,732	1,798,283		
1957	17,890,612	15,386,348	2,504,264		
1958	20,100,130	16,934,340	3,165,290		
1959	23,713,618	18,871,474	4,119,032	26,903	696,209
1960	30,588,031	23,765,405	5,065,420	831,989	925,217

Figure 65.

GENERALIZED STRATIGRAPHIC CORRELATION CHART

SHOWING PRODUCING HORIZONS—MONTANA GAS FIELDS—1961

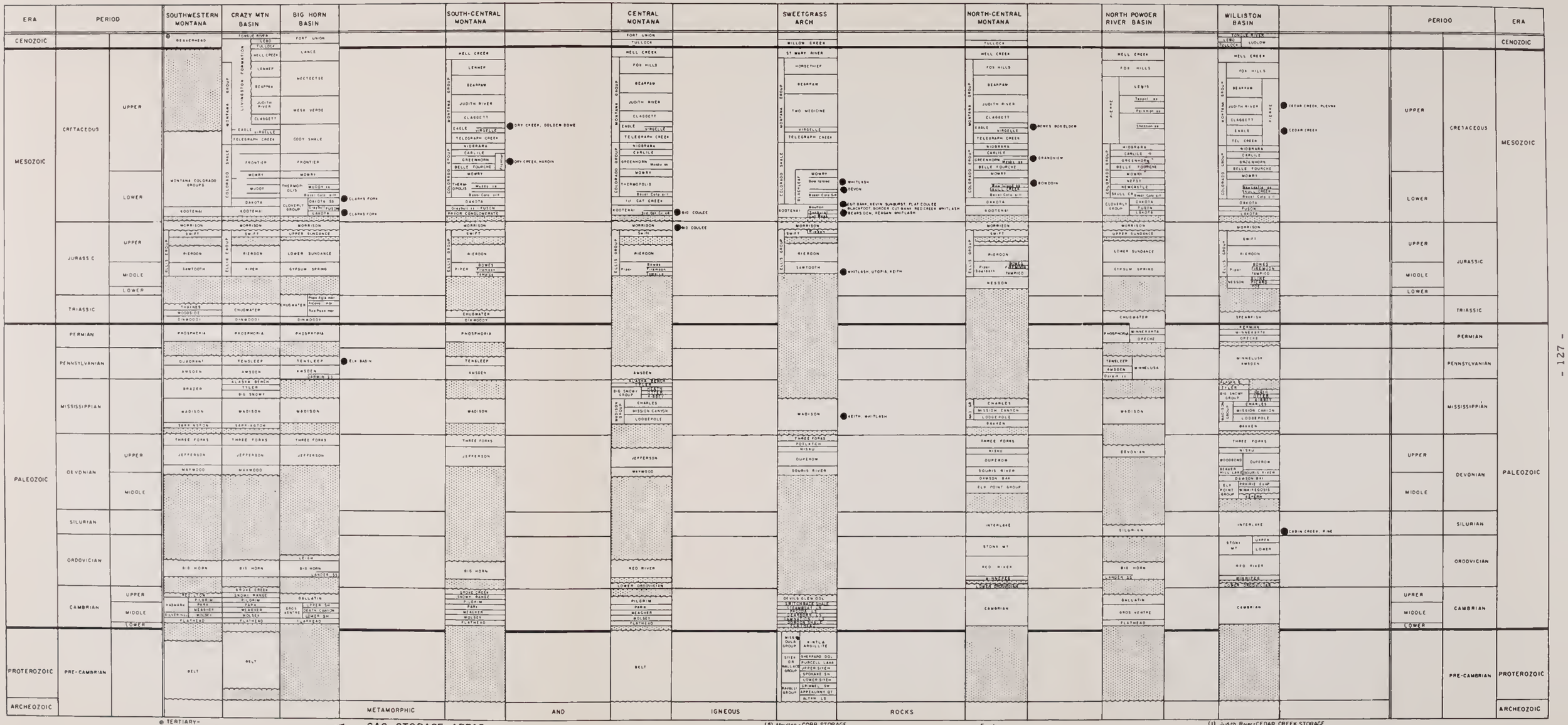


Figure 66

Stratigraphy and Structure Relative to Gas Storage

Stratigraphic Section

The accompanying stratigraphic chart (figure 66) clearly summarizes the gas producing intervals and the storage area.

Structure of Gas Storage Areas

The detailed structure map will be discussed under the separate storage areas.

Gas Storage Projects in Montana

Cedar Creek

Location. - The Cedar Creek Gas Field in southeastern Montana lies principally in Fallon County and extends over into Bowman County in western North Dakota for a short distance. The productive area is approximately 52 miles long by 4 1/2 to 5 miles wide (see figure 67).

The gas field lies upon the crest of the Cedar Creek Anticline, a regional geologic structure approximately 125 miles in length, extending from central Dawson County, Montana, through Bowman County, North Dakota, to Harding County, South Dakota. From the North Dakota state line, southeast of Baker, Montana, it plunges northwest to obscurity in the Sheep Mountain Syncline of Dawson County. The anticline is characterized by a steep dipping (5 to 30 degrees) west flank and gently dipping (1 to 8 degrees) east flank.

Several local domes are superimposed along the crest of the regional feature. These include Gas City, Cabin Creek, Baker, Hidden Water, and Little Beaver domes.

Faulting occurs along the steep dipping west flank of the anticline with the major zones of weakness parallel to the anticlinal axis.

Erosion has stripped all formations above the Bearpaw from the crest of the anticline leaving the Bearpaw Member of the Pierre Shale exposed along the anticlinal crest.

The Judith River and the Eagle Sandstones are the two gas-producing strata on the Cedar Creek Anticline, the Judith River being more widespread and productive. The Judith River is found at depths ranging from 700 to 1,100 feet along the anticline. The average depth of the storage area of Units 2, 3, 4, and 5 is 800 feet. It is the Judith River Formation in which Montana-Dakota Utilities Company is storing natural gas.

History of Development. - Gas was discovered on the Cedar Creek Anticline in 1913 when Midwest Oil Company drilled on the Gas City Dome in the NE NE Section 20, Township 14 North, Range 55 East. Production was from the Judith River Formation at an approximate depth of 750 feet. The gas from this dome was marketed in Glendive until 1926, at which time this local area was abandoned.

In 1915 a well drilling for water near Baker obtained a considerable flow of gas which caught fire and burned until it was extinguished in the fall of 1921. The strongest flow of gas then discovered was that of a well on the Cabin Creek Dome, drilled in 1917. This well is reported to have had an initial production of 10 million to 12 million cubic feet per day. During the period 1915 to 1926, gas completions in the Baker Cabin Creek areas ranged from 1 to 10 per year. The predominate drilling activity was in the years 1925 to 1931. By 1950 there were some 250 producing or producible gas wells along the Cedar Creek Anticline.

Most pipelines from the field were constructed during the period from 1926 to 1930. Gas from the field was supplied via pipelines to various cities and towns in Montana and the Dakotas.

The Cedar Creek Gas Field is operated under unit agreements by the Montana-Dakota Utilities Company, which is a cooperative plan for the development, conservation, and operation of the field. The areas considered proven are divided into nine units - Unit 1 (now abandoned) on the northwest edge of the field and the other units occupying successive areas southeastward through Unit 8-B. These units are independent of each other, each working interest owner and mineral owner receiving his pro rata share of production

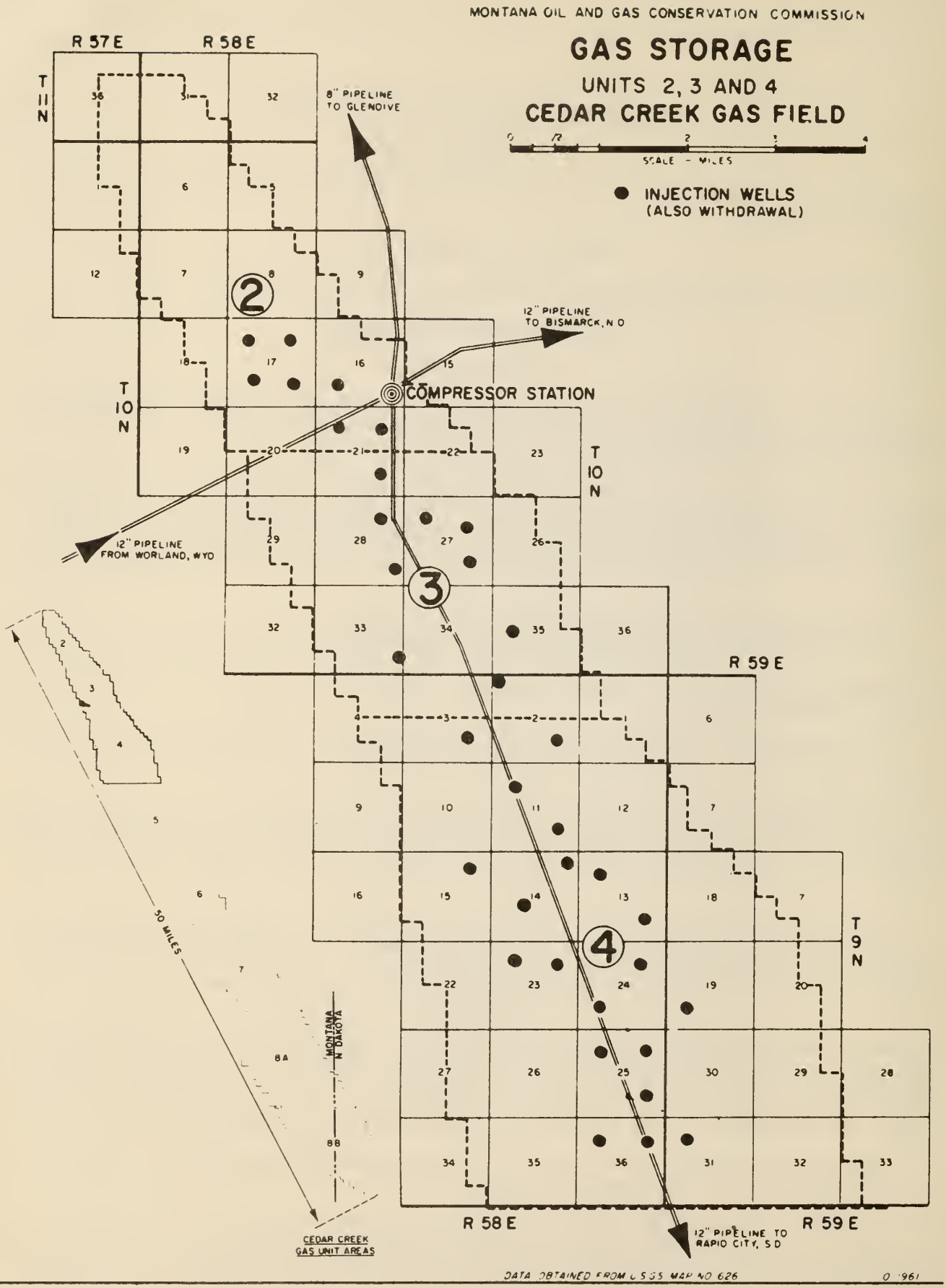

MONTANA OIL AND GAS CONSERVATION COMMISSION
GAS STORAGE
UNITS 2, 3 AND 4
CEDAR CREEK GAS FIELD
SCALE - MILES
INJECTION WELLS
(ALSO WITHDRAWAL)
R 57 E
R 58 E
R 59 E
T 11 N
T 10 N
T 9 N
8" PIPELINE TO GLENDIVE
12" PIPELINE TO BISMARCK, N D
COMPRESSOR STATION
12" PIPELINE FROM WORLAND, WYO
12" PIPELINE TO RAPID CITY, S D
50 MILES
MONTANA
N DAKOTA
CEDAR CREEK GAS UNIT AREAS
DATA OBTAINED FROM U S G S MAP NO 626

Figure 67.

within the specific unit area in which their properties are located.

In May, 1945, Montana-Dakota Utilities commenced storage of gas into the Judith River Formation in Unit 2. In the summer months gas was transferred from the Bowdoin Field in northern Montana to Cedar Creek. The stored gas was used in the winter months to help carry the load supplied by Cedar Creek. Subsequently, arrangements were made to obtain available gas in Wyoming for injection and storage in Cedar Creek. The storage reservoir is considered to underlie Units 2, 3, 4, and 5. The operator has injected gas into Units 2, 3, and 4 only, Unit 5 having no injection wells. The storage reservoir has not been consolidated into one unit operating agreement but continues to operate under the separate units.

The Storage Reservoir. - The Judith River Reservoir consists of alternating thin layers of sand and shale varying in thickness from a few inches to a few feet. The sand is erratic, varying from sandy shale to shaly sand with interbedded clay or silt. Some areas to the southeast appear to have thin zones of relatively pure sandstone, but laminae of clay and silt are also present. The net pay thickness of the upper Judith River gas bearing zone averages 60 feet, and the porosity averages from 10 to 15 percent. Initial wellhead pressures averaged 210 to 220 pounds per square inch for Judith River wells. Initial production of Judith River wells averaged 15 million cubic feet of gas per day, with low initials of 1 million cubic feet per day to high initials of 28 million cubic feet per day.

It was stated above that the gas is considered to be confined to Units 2, 3, 4, and 5. Actually, there is a continuity of sand across the entire field; however, low permeabilities in Units 5 and 6 prevent widespread movement. Migration of gas to the southeast would be dependent upon the pressure subjected to the reservoir which in turn is dependent upon the net gain in the volume of gas in the reservoir as a result of injection. Naturally, the high pressure areas are adjacent to the injection wells, and pressures successively decline with distance from injection wells. The pressure, therefore, at any one point in the reservoir is a function of the pressure in the surrounding injection wells.

High pressure areas in the storage reservoir are in Units 3 and 4. The common corner of Sections 21, 23, 27, and 28, Township 10 North, Range 58 East, of Unit 3 has relatively high pressures ranging up to 114 psi. The northeast quarter of Section 14 of Unit 4 has relatively high pressures up to 102 psi. Average pressures of the Judith River Storage Reservoir by units as of April, 1961, are as follows: Unit 2, 102.1 psi; Unit 3, 98.7 psi; Unit 4, 85.1 psi; Unit 5, 65.5 psi.

Although no gas is being injected directly into Unit 5, and the nearest injection wells are 1 3/4 miles from the Unit 5 boundary line, migration of gas is taking place from Unit 4 into Unit 5 as indicated by a comparison of pre-injection and present pressure data. Rock pressures of wells in northwest Unit 5 are increasing as the net gain of storage gas increases, but not proportionally, and this pressure increase is indicative of migration.

Reservoir energy is primarily from gas expansion. Edge water encroachment appears inactive as indicated by a pressure differential of over 100 pounds between present and original pressures (less than half that of the 210 pound original pressure). If an active water drive were present, the reservoir should be nearer the original rock pressure at the present and producing larger quantities of water.

There are a total of 22 injection wells in the storage reservoir, distributed as follows: Unit 2, 6 wells; Unit 3, 4 wells; Unit 4, 12 wells. All injection wells serve the dual purpose of production and injection.

Cedar Creek Gas Storage began in 1945.

Number of acres	80,100
Estimated Pre-injection Recoverable Reserves 5/45	16,018,000 Mcf
Net gain in Gas Storage	30,588,031 Mcf

Madison Valley Storage

Location. - The acreage required for the storage project (figure 68) is located in the southwestern part of Township 1 North, Range 2 East, Gallatin County. It is located approximately six miles south-southeast of the town of Three Forks. This is a Montana Power Company project.

General Geology. - The storage reservoir consists of a series of water filled sands of the Bozeman Lake beds which are believed to be of the Tertiary age. These sands are found at very shallow depths and

occur intermittently to the Precambrian formation which underlies this area.

A seismic program was carried out on part of this area but gave negative results as to the structure of the Tertiary or storage sands. However, control on the Precambrian or basement rock underlying the storage area was considered good.

The injection sand selected lies approximately 1,190 to 1,270 feet below the surface. The sand ranges from a few feet in some wells to greater than 40 feet in others. The sand has a porosity up to 36%, and permeabilities vary from less than one to more than 4,000 millidarcies. Original hydrostatic pressure at this depth was calculated to be 467 pounds per square inch. Another sand at a depth of 850-900 feet is being considered for possible gas storage.

Development. - This project was an experimental development employing a water filled formation. It was one of the first of this type employed in the United States and had little or no assistance from prior experience for this type of gas storage.

The first test well, the Frances No. 1, was started in May of 1952 and was drilled to a total depth of 1,182 feet. Most of the well was cored, and core analyses indicated the project should be continued.

Fifteen additional wells were drilled, and an old well was cleaned out and completed. Intervals of all wells were cored, and electrical logs were run on the seventeen wells before casing was set. Of the sixteen new wells drilled, two were plugged and abandoned.

Box Elder Storage

Location. - The Box Elder structure (figure 69) is located in Township 32 North, Ranges 17 and 18 East, on the common line of Hill and Blaine Counties, Montana. The foothills of the Bearpaw Mountains are approximately five miles southwest of the Box Elder area. This is a Montana Power Company project.

General Geology. - The Box Elder Storage is located on an elongated northwest-southeast trending domal structure that is cut by a northeast-southwest trending fault (see figure 69). The Eagle Sandstone into which the gas is to be injected is approximately 200 feet thick in this field. It consists of three members. The lowermost of these is the Virgelle sand which is approximately 100 feet thick. It is micaceous glauconitic sand containing shaly members. There is a 25 foot bed of grey shale and siltstone separating the Virgelle from the overlying productive sandstone. This sand is a grey glauconitic sandstone some 80 feet thick. Porosities and permeabilities vary with the shale content in this upper sand. The fault that cuts across the structure is an effective barrier. This is indicated by pressure differences between wells on the north and south. Gas storage is at present confined to the area south of the fault.

Injection pressure - 300 psig to 420 psig.
Total of 1,034,868 Mcf added (net) to storage as of July 1, 1961.
Acres - 2,640.

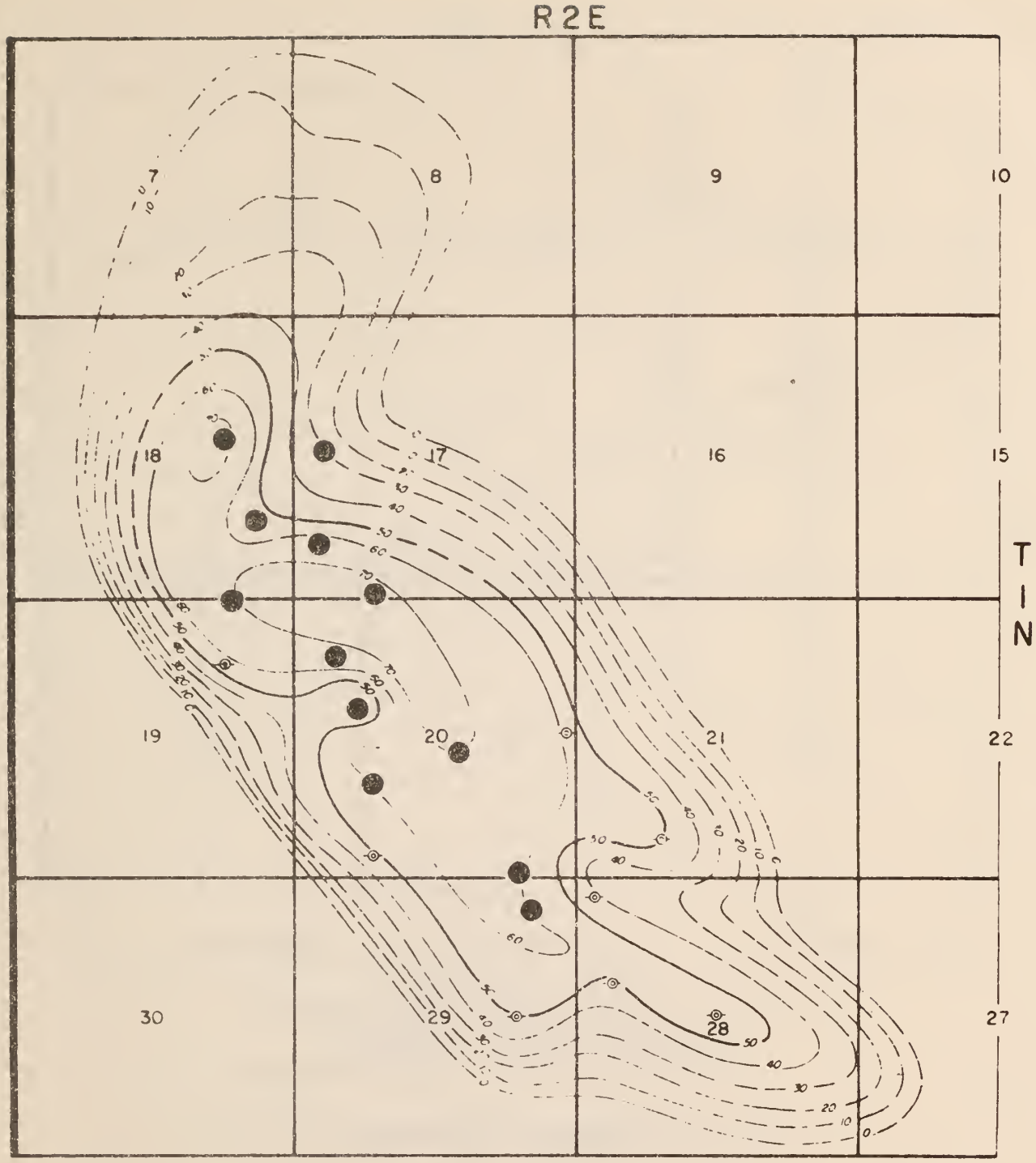
Shelby Gas Storage

Location. - The Shelby Gas Storage Project is located (figure 70) in the southern portion of the Kevin-Sunburst Gas Field within Section 13, E 1/2 Section 14, N 1/2 NE 1/4 Section 23, and N 1/2 N 1/2 Section 24, Township 32 North, Range 2 West, Toole County, Montana.

Geology. - The Shelby Gas Storage Project lies on the south slope of the Kevin-Sunburst Dome approximately 12 miles from the crest of the structure. The "storage sand" is the nearly depleted Sunburst Sandstone of the lower Cretaceous age. It is separated from the Ellis Shale of Jurassic age by a yellow shale. This shale serves as an easily recognized geological marker over much of the area of the Kevin-Sunburst Field. The Sunburst Sandstone varies in thickness from zero to more than 35 feet and varies greatly in porosity and permeability.

The Sunburst Sandstone in the storage area is shut off from other areas of the Kevin-Sunburst Gas Field by the thinning of the sand body or by porosity and permeability pinchouts to the west, north and east. To the south and southwest the productive area is confined by an encroaching water table.

Development. - Four wells have produced gas in commercial quantities from this small stratigraphic



MONTANA OIL AND GAS CONSERVATION COMMISSION

MADISON GAS STORAGE

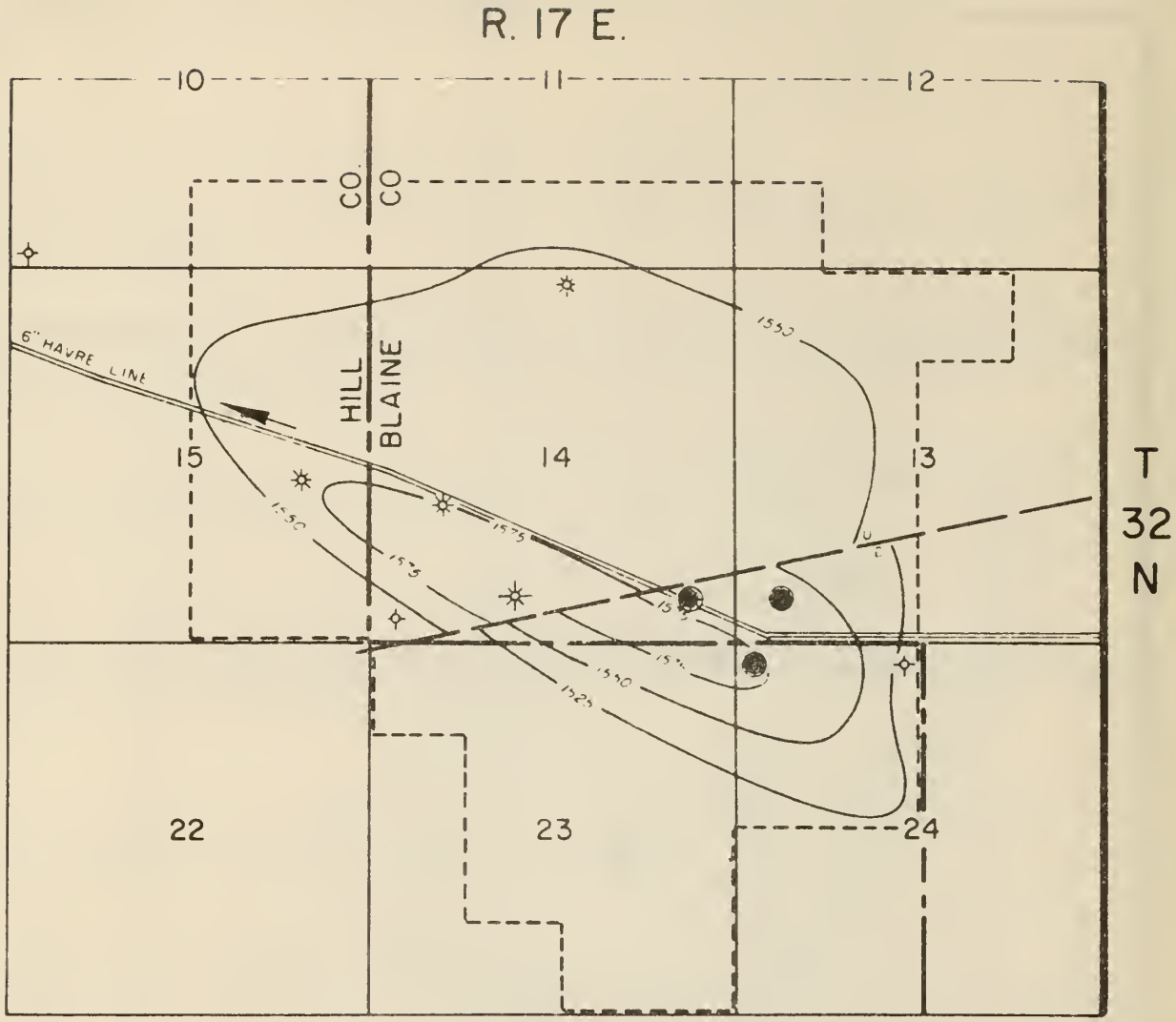
GALLATIN COUNTY, MONTANA

Injection and Withdrawal Wells (12)

Water Relief Wells

Isopach Contours on Tertiary Storage Sand, CI = 10'

Figure 68.



MONTANA OIL AND GAS CONSERVATION COMMISSION

GAS STORAGE
BOX ELDER FIELD

BLAINE AND HILL COUNTIES, MONTANA

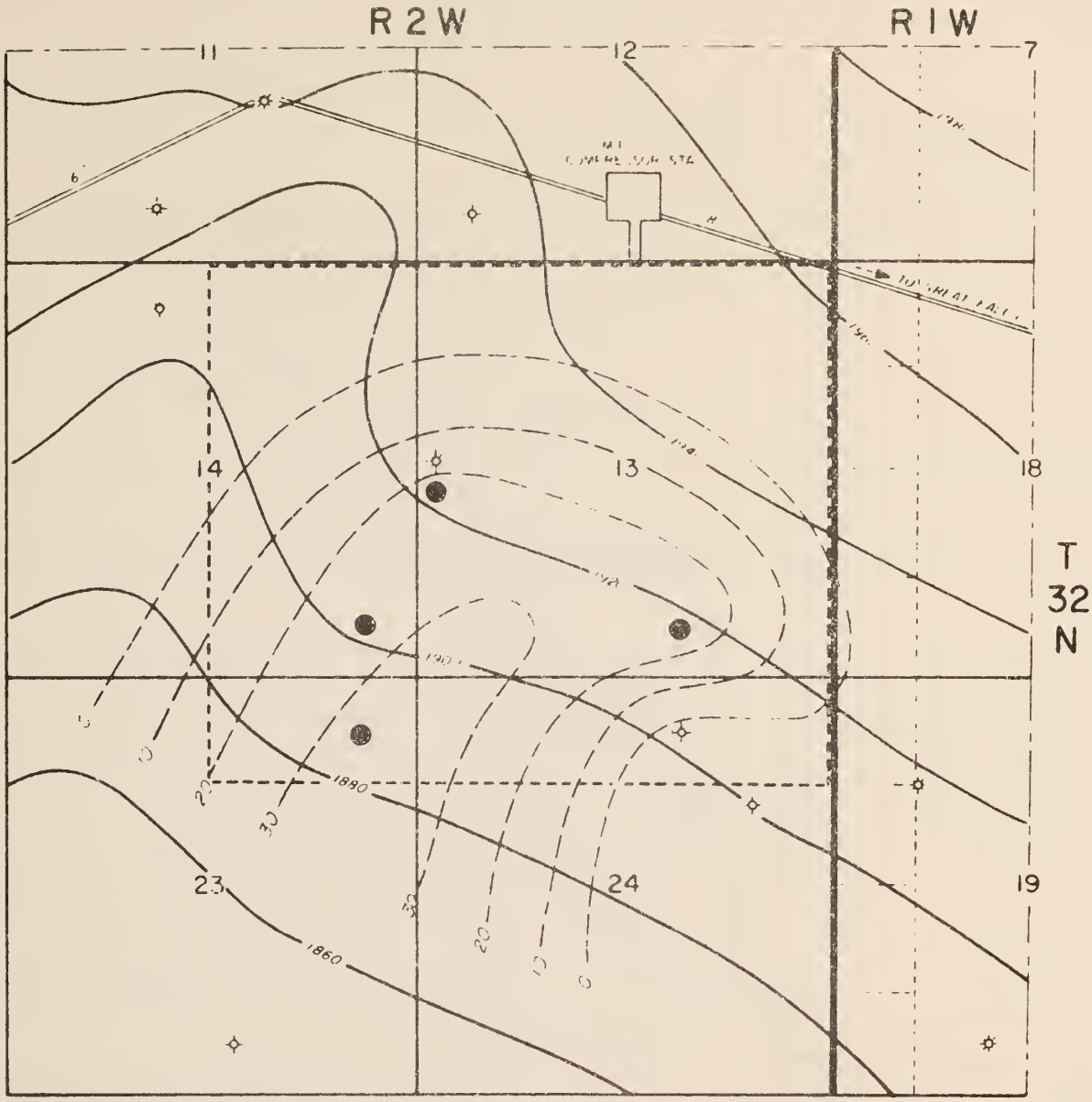
0 1/4 1/2 3/4 1

SCALE - MILES

☼ Producing Wells
● Injection and Withdrawal Wells (3)
----- Boundary Line of Storage Rights

Contoured on top of Eagle Gas Sand, Contour Interval = 25'

Figure 69.



MONTANA OIL AND GAS CONSERVATION COMMISSION

SHELBY GAS STORAGE

TOOLE COUNTY, MONTANA

✡ Producing Wells

● Injection and Withdrawal Wells (4)

---- Boundary Line of Storage Rights

Contoured on base of Sunburst Sand, Contour Interval = 20'
Effective Porosity – Isopach of Sunburst Sand
— — Isopach Contours, C.I = 10'

DATA OBTAINED FROM DOCKET 18-59 MPCO

Figure 70.

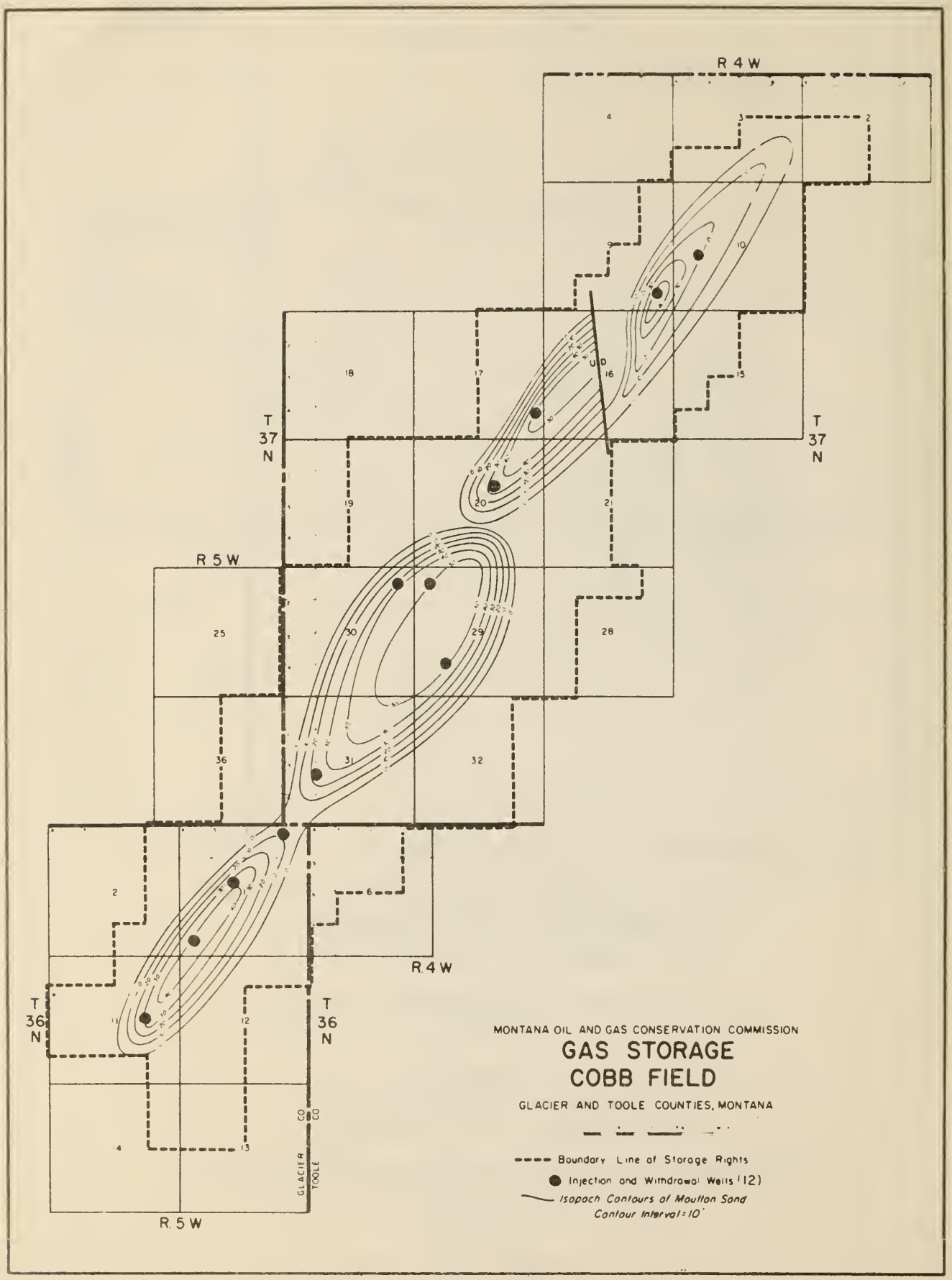

R 4 W
T 37 N
R 5 W
T 36 N
R. 4 W
R. 5 W
GLACIER CO
TOOLE CO
MONTANA OIL AND GAS CONSERVATION COMMISSION
GAS STORAGE
COBB FIELD
GLACIER AND TOOLE COUNTIES, MONTANA
Boundary Line of Storage Rights
Injection and Withdrawal Wells (12)
Isopach Contours of Moulton Sand
Contour Interval = 10'

Figure 71.

trap. Three of these wells were flooded by down-dip water. The fourth was reworked for an injection well.

It has been estimated that the original Shelby Storage area contained some 775 acres. When injection began, there was approximately 800 MMcf of gas remaining below abandonment pressure.

This is a prime example of a small depleted gas field being used as an effective gas storage area.

Total of 1,261,135 Mcf added (net) to storage as of July 1, 1961.
Acres - 1,200.

Cobb Storage Project

On September 20, 1961, approval for this storage unit was granted by the Montana Oil and Gas Conservation Commission.

Location. - The Cobb Storage area is located in the northerly portion of the Cut Bank Field in Glacier and Toole Counties, Montana. The project area covers 8,920 acres and lies in a northeast-southwest direction (see figure 71).

Geology. - The Moulton Sand will be the storage sand in the Cobb Gas Storage area. It is found approximately two hundred feet above the Ellis Shale in the Kootenai Formation of the Cretaceous age. It is made up of several sand bodies of very limited width trending in a northeast-southwest direction beginning near the Canadian border in Section 3, Township 37 North, Range 4 West to Section 7, Township 35 North, Range 5 West, for a distance of approximately 16 miles in a remarkably straight line. Along this trend there are one oil and four separate gas pools. The two northeasterly pools are those included in the Cobb Gas Storage area. The Moulton Sand, where productive, is a salt and pepper sand made up of well sorted medium to coarse grained chert and quartz grains. Along the flank of the lenses the sand grades into a dark green, very hard, non-porous, tight, fine-grained sandstone. This tight sandstone is deposited over most of the Cut Bank Field and is non-productive throughout.

Structural position apparently has very little effect upon the accumulation of the gas in the Moulton Sand as it produces in the synclines on top of the anticlinal axis and along the flanks of structural "noses".

Complete separation of the gas pools was probably caused by stream erosion following deposition of the sand, after which the stream channels filled with silty, nonporous materials.

There is one recognizable fault in the project which trends west of north through the approximate center of Section 16, Township 37 North, Range 4 West. It is a scissor-type fault without enough development in the southern portion to isolate the sand on either side of the fault.

Development. - The first well of consequence in the Cobb area was the Cobb-State, NE 1/4 NE 1/4 Section 30, Township 37 North, Range 4 West. It was drilled in 1937, and a pipeline connection was put in in 1945. In 1949 the Cobb Unit was formed, and it has produced 9,449 MMcf. Montana Power Company owns all the gas wells in the storage unit.

Regulations Affecting Storage Projects in Montana

Commission Rule 229

"229.1 Application and Approval

The owner of any well may inject gas under pressure into the formation for the purpose of storing such gas or obtaining other oil or gas from the reservoir, upon application to and approval by the Commission.

"229.2 Casing and Cement

Wells used for the injection of gas shall be cased with solid casing so as not to permit leakage and the casing cemented in such manner that damage will not be caused to oil, gas, or fresh water resources.

"229.3 Application, Contents, Notice, Objection, Hearing and Approval

(a) No gas shall be injected into a well for gas injection purposes until so ordered by the Commission pursuant to application, and notice as herein required.

(b) The application shall be filed with the Commission showing:

1. the location of the input well;
2. the location of all oil and gas wells, including abandoned and drilling wells and dry holes, and the names of the owners of any interests of oil and gas within the limits of the gas injection project;
3. the formation from which wells are producing or have produced;
4. the name, description, and depth of the formation to be injected;
5. the elevations of the top of the oil or gas bearing formation in the input well and the wells producing from the same formation within the limits of the gas injection project;
6. the log of the input well, or such information as is available;
7. description of the input well casing;
8. description of the gas, stating kind, where obtained, and estimated amount to be injected daily;
9. the names and addresses of the operators within the limits of the gas injection project;
10. such other information as the Commission may require to ascertain whether the gas injection plan meets the requirements of the law and safety.

(c) Application may be made to include the use of more than one input well on the same lease or on more than one lease.

(d) Application shall be executed by all operators who are to participate in the proposed gas injection plan.

(e) Notice of application shall be given by the applicant by mailing or delivering a copy of the application to each operator of drilling or producing well or wells which have produced within one-half mile radius of the proposed input well. Such notice shall be mailed or delivered on or before the application is mailed to or filed with the Commission.

(f) Objections or complaints, stating the reasons why the proposed plan as contained in the application may cause damage to oil, gas or fresh water resources must be filed within ten days after the application is filed.

(g) In the event any such objection or complaint is filed or the Commission on its own motion deems that there should be a hearing on the application, a hearing shall be had after reasonable notice of the time, place and subject matter of such hearing has been given.

(h) Orders approving the plan will not be made within ten days of the filing of the application unless the written consent of all persons entitled to notice is filed with the Commission within such time.

"229.4 Notice of Commencement and Discontinuance of Gas Injection

(a) Immediately upon commencement of gas injection operations, the applicant shall notify the Commission of the same and the date of commencement.

(b) Within ten (10) days after the discontinuance of gas injection operations, the applicant or the one in charge thereof shall notify the Commission of the date of such discontinuance and the reasons thereof.

(c) Before any input well shall be abandoned, notice shall be served on the Commission and the same procedure shall be followed in the plugging of such well as provided for the plugging of oil and gas wells.

"229.5 Records

The owner or operator of the gas injection project shall keep an accurate record of (1) the amount

of gas injected into the input wells, the wellhead pressures, (2) the amount of gas produced, and (3) the amount of oil produced from leases affected by the gas injection. Such information shall be filed with the Commission.

229.6 Individual Cases

The Commission will make such special orders, rules, and regulations for the individual case as the condition may justify."

NEVADA

Robert C. Horton, Mining Engineer
Nevada Bureau of Mines

There are no gas wells in Nevada nor any facilities for the underground storage of gas. Cavities for the storage of gas could be excavated by underground mining methods, but such should be the case in most states.

At the present time there is little known concerning the subsurface conditions as regards permeability and porosity of most of the sedimentary formations in Nevada. The broad structural features within the state are generally known, and some detailed structural mapping is under way. At the present time too little knowledge of subsurface conditions is available to be able to make specific comments regarding the location or feasibility of underground storage of gas.

NEW HAMPSHIRE

T. R. Meyers, State Geologist
New Hampshire State Planning and Development Commission

Production and Utilization of Natural Gas in New Hampshire

Small quantities of methane and related gases are being generated in post-Pleistocene bog, swamp, and saltmarsh deposits. None of these gases is used currently.

Natural gas pipelines originating in the southwestern states have been extended to the larger southern New Hampshire communities in recent years, replacing locally manufactured coal gas. The use of bottled natural and petroleum gases is rapidly increasing in villages and rural areas.

Bed Rock Geology

The stratigraphic units are of Ordovician, Silurian, and Devonian age. They consisted originally of silicious and aluminous sediments and volcanics. Carbonates are rare. All have been metamorphosed. Quartzites, phyllites, and schists, some sillimanite-bearing, are the most common lithologic types now exposed.

The major fold structures are northerly to northeasterly-trending anticlinoria and synclinoria. Iso clinal folding is common. Thrust and normal faults are present.

Intrusive igneous rocks and structures are common. To date, four magma series have been identified. These are, from oldest to youngest, the Highlandcroft, the Oliverian, the New Hampshire, and the White Mountain series.

Underground Storage of Natural Gas

The possibility of storing gas in natural underground reservoirs seems remote. Such rock porosity determinations that have been made by the writer are of the order of one-half percent or less.

Storage is possible in artificial openings in the bed rock.

Abandoned underground mines are present in the state. A survey might reveal that one or more of these possesses the necessary characteristics of size, location, and rock properties to warrant its use. If not, one or more openings could be developed in desirable locations for storing natural gas.

NEW YORK[1]

William Lynn Kreidler, Senior Geologist
Geological Survey
New York State Museum and Science Service

General Historical Remarks

In New York State, numerous natural gas seepages were known to exist during early Colonial times. The first successful gas well was completed in the Upper Devonian, at Fredonia, New York, in 1821. At the time of General Lafayette's visit to western New York on June 4, 1825, natural gas lighted the village of Fredonia. This is believed to be the first use of natural gas on the North American continent.

Gas-Producing Formations in New York

As mentioned above the original gas production came from the Upper Devonian and was the incentive for the search for gas in the deeper horizons. This gas was used for local consumption and was found in the following counties: Chautauqua, Erie, Cattaraugus, Allegany, and Steuben.

Gas production has been found in paying quantities for local consumption in the Tully Limestone and Hamilton Group of Middle Devonian age. This gas was discovered in the following counties: Allegany, Chemung, Livingston, Ontario, Schuyler, and Yates. The majority of the shallow Devonian gas fields are now exhausted or supply only a small amount of gas to the farms on which the wells are located.

The first Medina gas well, Silurian in age, was drilled in 1858 or 1859 at Getzville, Erie County, New York. Since this time the Medina has been one of the most reliable and steadiest gas producing horizons in the state. The most important Medina gas fields are found in the counties of Ontario, Genesee, Erie, Chautauqua, and Cattaraugus. Less productive Medina gas fields have been found in Wyoming, Monroe, and Seneca Counties. A number of the Medina gas fields, which have been exhausted in Cattaraugus, Chautauqua, Erie and Wyoming Counties, are now used as storage fields (see figure 72).

The first production of gas from the Onondaga-Oriskany, previously called Onondaga-Salina, was in 1886 in the Zoar Valley, Erie County, New York. Other wells were soon completed, and a pipeline was laid into Springville in 1894. By 1914, the rock pressure had declined to 100 psi, and during the winter of 1914-1915 and 1915-1916 the wells were put on suction. In 1916, the rock pressure had been pulled down to approximately 50 psi, and storage operations were commenced on a minor scale. These operations proved so successful that the Zoar Field has been used continually by the Iroquois Gas Corporation for underground storage of gas (see table 27). The first attempt to store gas underground in North America was in Welland County, Ontario Province, Canada, in 1915. This was followed by the Iroquois Gas Corporation storage pool in the Zoar Field in 1916.

In 1888, the first gas production from the Trenton Limestone (Ordovician in age) was found in Wayne County, New York. At a later date, Trenton gas production was discovered in the following counties: Erie, Lewis, Oneida, Onondaga, Oswego, and Wayne. This gas was used for local consumption. All of the Trenton fields are now exhausted or supply only a small amount of gas to the farms on which the wells are located.

The search for Oriskany gas, Devonian in age, in the southern and southwestern counties of New York and northcentral Pennsylvania was instigated in 1928 by the discovery of gas in the Gilbert No. 1 from the Tully Limestone at 3,990 feet in Allegany County, New York. The discovery of gas in the Oriskany sand (Lower Devonian) from the Wayne-Dundee Field, Schuyler County, New York, on February 26, 1930, resulted in a gas boom in western New York that reached its peak production in 1938. The Oriskany gas fields are located in Allegany, Cattaraugus, Schuyler, Steuben, Tompkins and Yates Counties. A few of the Oriskany gas fields, which have been exhausted in Schuyler, Steuben and Yates Counties, are now used as storage fields (see figure 72).

On the Mower farm in the township of Phelps, Ontario County, on August 7, 1932, an unexpected large flow of gas was found 111 feet below the top of the Lockport, Silurian in age. By the fall of 1934,

[1] Published by permission of Assistant Director, New York State Museum, Journal Series No. 45.

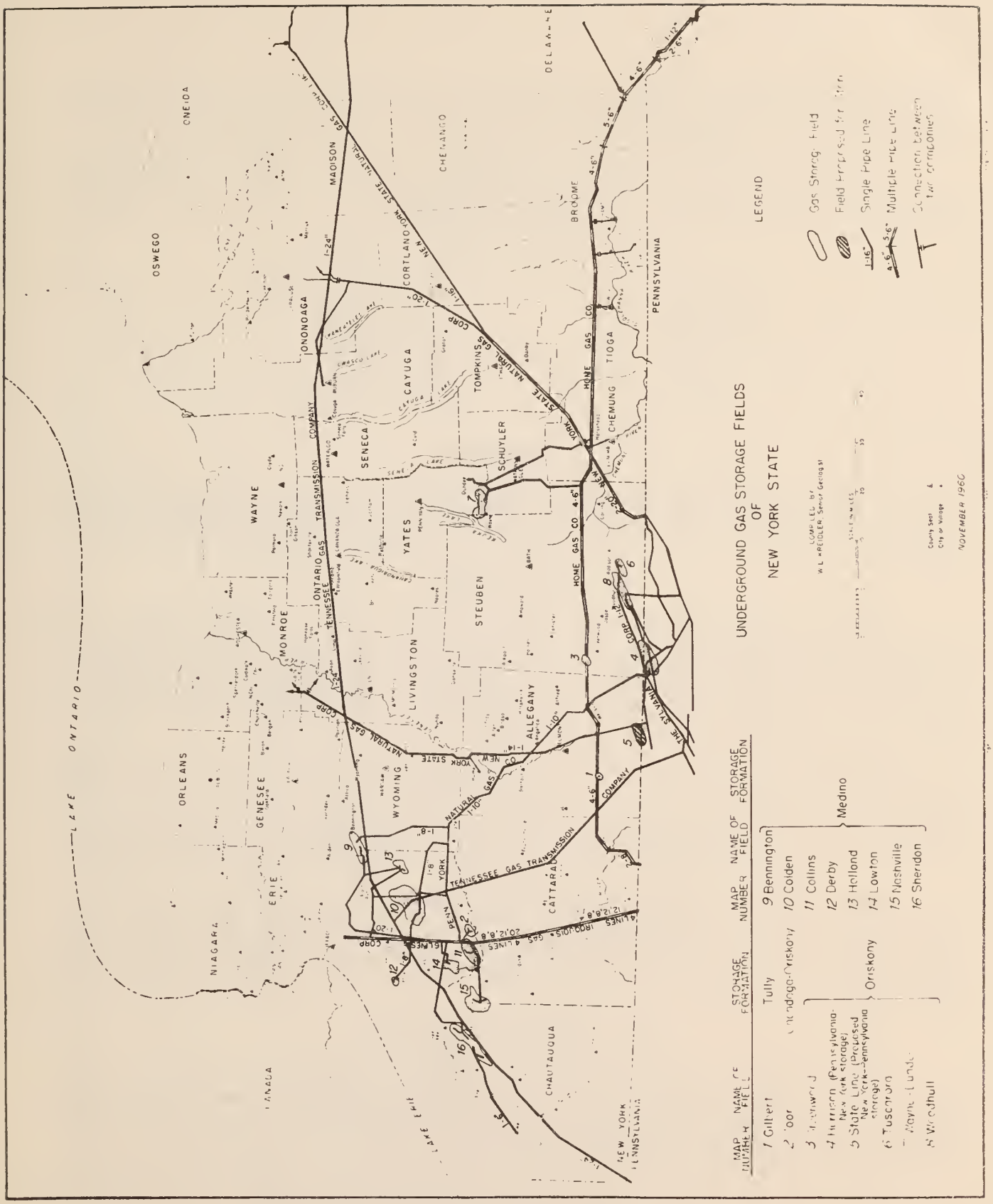

UNDERGROUND GAS STORAGE FIELDS
OF
NEW YORK STATE
LEGEND
Gas Storage Field
Single Pipe Line
Multiple Pipe Line
NOVEMBER 1960
MAP NUMBER
NAME OF FIELD
STORAGE FORMATION
1 Gilbert
2 Poor
3 Greenwood
4 Harrison (Pennsylvania-New York storage)
5 State Line (Proposed New York-Pennsylvania storage)
6 Tuscarora
7 Wayne-Dundee
8 Woodhull
Tully
Onondaga-Oriskany
Oriskany
9 Bennington
10 Colden
11 Collins
12 Derby
13 Holland
14 Lowton
15 Nashville
16 Sheridan
Medina
OSWEGO
ONEIDA
MADISON
CHENANGO
DELAWARE
BROOME
PENNSYLVANIA
ONONDAGA
CORTLAND
CAYUGA
TOMPKINS
TIOGA
CHEMUNG
SENECA
SCHUYLER
WAYNE
YATES
STEUBEN
MONROE
LIVINGSTON
ALLEGANY
ORLEANS
GENESEE
WYOMING
ERIE
NIAGARA
CATTARAUGUS
CHAUTAUQUA
LAKE ONTARIO
LAKE ERIE
NEW YORK STATE NATURAL GAS CORP
TENNESSEE GAS TRANSMISSION COMPANY
HOME GAS CO
NEW YORK STATE NATURAL GAS CORP
NATURAL GAS CO
PENN YORK
THE SYLVANIA
NEW YORK PENNSYLVANIA

Figure 72.

a total of 66 wells had been drilled in the Geneva Field without any actual distribution of gas. Several months after the wells were connected into the line, the gas pressure dropped until it equalled the line pressure of 40 to 50 psi. This, in a commercial sense, meant that the field was exhausted.

The Oriskany Formation and the Medina Formation are the major gas-producing horizons in the State of New York. No records are available on gas production in New York prior to 1897. The production figures appearing in the table below from 1897-1903 are estimated:

Table 26 - New York State Gas Production

1897-1903	20,000,000 Mcf Est.
1904-1933	195,931,693 Mcf
1934-1948	43,196,000 Mcf
1949-1959	39,545,289 Mcf
Grand total	298,682,982 Mcf Est. produced to January 1, 1960

Gas Reserves

As of January 1, 1952, the total natural gas reserves of New York State were estimated at 63 billion cubic feet. As of January 1, 1960, the total natural gas reserves are estimated at 82 billion cubic feet. The increase is due to the discovery of an Oriskany field in Cattaraugus County and a Medina field in Ontario County.

General Geology

The surface geology of western and central New York shows the older Paleozoic rocks progressively overlain southward by younger Paleozoic rocks in the Allegheny synclinorium. The regional dip is away from the Precambrian highs which in western New York is the Canadian Shield of Canada and in eastern New York are the Adirondack Mountains and the Hudson Highlands. Therefore, the Ordovician Queenston Formation is exposed south of Lake Ontario and is overlain to the south by the Silurian formations which in turn are overlain southward by the Devonian formations.

The structural and stratigraphic features of the Silurian Medina Formation and the Devonian Oriskany Formation will be briefly discussed, as they are the major producing and underground gas storage horizons. The main structural feature of the Medina is a southerly dipping homocline upon which are superimposed several structural terraces on which a number of the gas and storage fields are located. In these fields the gas is accumulated in the porous sandstone and is sealed by the impervious parts of the reservoir. In a few cases drilling has indicated the presence of structural closure.

Southeast and south of the Medina fields are the Oriskany gas and storage fields. In drilling for Oriskany gas, wells have proved the existence of anticlines, synclines and faults. The structural traps along the anticlinal trends are complicated by faults which parallel the axial trends and in places cross these axial trends. The Oriskany gas is controlled by anticlinal or structure traps and in a few instances by the stratigraphic pinch-out of the Oriskany Sandstone. Up to the present, all Oriskany gas storage fields are anticlinal or structural traps.

Gas Storage Projects in New York

At present there are 14 gas storage projects (see figure 72) in the State of New York with a total storage capacity of 94,469,777 Mcf of gas. The above total can be broken down in the following manner: cushion gas - 42,755,000 Mcf, working gas - 51,714,777 Mcf. The amount of acreage (working and controlled) held by the operators for the 14 gas storage projects (see table 27) is estimated to be 151,500 acres. As of January 1, 1960, there were 646 active storage wells.

Table 27 lists all the gas storage projects in the State of New York and gives pertinent data on each project. The information for table 27 was furnished by the operating companies.

The map showing the underground gas storage fields in New York does not indicate the Medina and Oriskany gas fields that are still active. Most of the main gas transmission lines with lines entering the

Table 27 - Underground Storage Data for New York State, December 1960

PROJECT	GILBERT	WOODHULL	WAYNE-DUNDEE	TUSCARORA	GREENWOOD
Operator	Home Gas Co.	N.Y.S.N.G.C.*	Home Gas Co.	The Sylvania Corp.	Home Gas Co.
County	Allegany	Steuben	Schuyler, Steuben, Yates	Steuben	Steuben
Township	Wirt	Woodhull Rathbone Troupsburg Tuscarora	Tyrone Wayne Barrington	Tuscarora	Greenwood
Discovery Date	9/11/1928	5/25/1937	2/26/1930	12/1/1944	1934
Number of Storage Wells	1	50	106	9	5
Original Rock Pressure	1860#	1950#	765#	1900#	1900#
Storage Formation	Tully Ls	Oriskany Ss	Oriskany Ss	Oriskany Ss	Oriskany Ss
Average Production Depth	3990'	4000'	2100'	3900'	4770'
Average Net Sand Thickness	50'	30'	10'	25'	10'
Date 1st Gas Injected	1940	1957	1940	1950	1942
Storage Capacity, when full	550,000 Mcf		10,500,000 Mcf		3,400,000 Mcf
Cushion Gas	325,000 Mcf	14,080,000 Mcf	6,000,000 Mcf	N.A.[2]	850,000 Mcf
Working Gas	224,294 Mcf	21,120,000 Mcf	4,395,593 Mcf	N.A.	924,890 Mcf
Total Gas	549,294 Mcf	35,200,000 Mcf	10,395,593 Mcf	5,200,000 Mcf	1,774,890 Mcf
Storage Pressure	2000#	1950#	765#	N.A.	2000#

*New York State Natural Gas Corporation

[2] Not Available

storage fields are shown. Storage field No. 4 indicates the Harrison Field that straddles the New York-Pennsylvania boundary line. The Harrison storage field has all its operations in Pennsylvania, but the original gas field extended into New York.

Possibilities of Expansion and Conclusion

The State Line Field, on the New York-Pennsylvania boundary line, is predominantly in New York and is planned for storage. This will be a joint venture by New York State Natural Gas Corporation and Tennessee Gas Transmission Company. This field will have an estimated storage capacity of 60,000,000 Mcf of gas. Iroquois Gas Corporation has asked the Federal Power Commission for a permit to develop an underground storage field near Perrysburg in Cattaraugus County. The cost is estimated at $1,692,000 including two miles of pipeline. It is expected, furthermore, as other gas fields are depleted, that a number of them will be converted to storage.

New York State is ideally located in northeastern United States for underground storage of natural gas and petroleum hydrocarbons. This is due to a ready market for natural gas in the large metropolitan areas in the east, especially New York City, and the equal need for this commodity in the New England States. It is anticipated that additional storage will be sought and continue to be at a premium in New York State.

NORTH CAROLINA

Jasper L. Stuckey, State Geologist
Division of Mineral Resources
Department of Conservation and Development

North Carolina lies across three major topographic provinces: the Coastal Plain on the east which includes approximately one-half of the area of the state, the Piedmont Plateau in the center which includes approximately 40% of the area of the state, and the Appalachian Mountains on the west which includes approximately 10% of the area of the state.

As the state is not and never has been a producer of oil and gas, there are no abandoned gas fields that can be used for underground storage. The only part of the state in which geological formations occur that give promise of containing oil and gas is the eastern half of the Coastal Plain. In this area between 1925 and 1959 inclusive, a total of 32 dry holes were drilled.

The map (figure 73) shows pipelines through which natural gas is brought into and distributed in North Carolina. Unfortunately this map does not show the size of the pipelines, and this information is not immediately available.

The Generalized Geologic Map (figure 75) of North Carolina shows the main geologic subdivisions of the state. The Piedmont and Mountain sections which include approximately half of the state are underlain with igneous, sedimentary, and metamorphic rock. The Precambrian gneisses and schists have been more or less completely metamorphosed. In addition to cleavage planes, they contain numerous joints and fractures. The Volcanic Slate Belt of late Precambrian or early Paleozoic age contains fragmental and flow rocks, some of which are true sediments that have been variously metamorphosed. In addition to some bedding planes and cleavage planes, they contain numerous joints and fractures. The Cambrian sediments consisting of quartzites, slates, shales, and limestones have been variously metamorphosed, and in addition to bedding and cleavage planes contain numerous joints and fractures. The Carboniferous rocks consisting essentially of granite and diorite are little metamorphosed. In general they are massive and lack cleavage planes, while jointing varies from none at Mount Airy to severe in places. The Triassic conglomerates, sandstones, and shales of continental origin are, in general, little metamorphosed. They are lenticular, cross bedded and, in general, highly impervious. As a result they are poor water-producing rocks. In general, deep wells in these rocks seldom yield over 10 to 25 gallons per minute.

The Coastal Plain of North Carolina is underlain with a wedge shaped block of sediments that varies in thickness from a featheredge along the western border to a maximum of 10,000 feet at Cape Hatteras. These sediments which are chiefly of marine origin and in general unconsolidated, consist of beds of sand and clay, clayey sands, and sandy clays, shell limestones, and marls that dip gently to the southeast and lie on crystalline rocks. Figure 74 shows these relations as well as the different ages of rocks present. However, only rocks of upper Cretaceous, Tertiary, and Pleistocene ages are exposed at the surface.

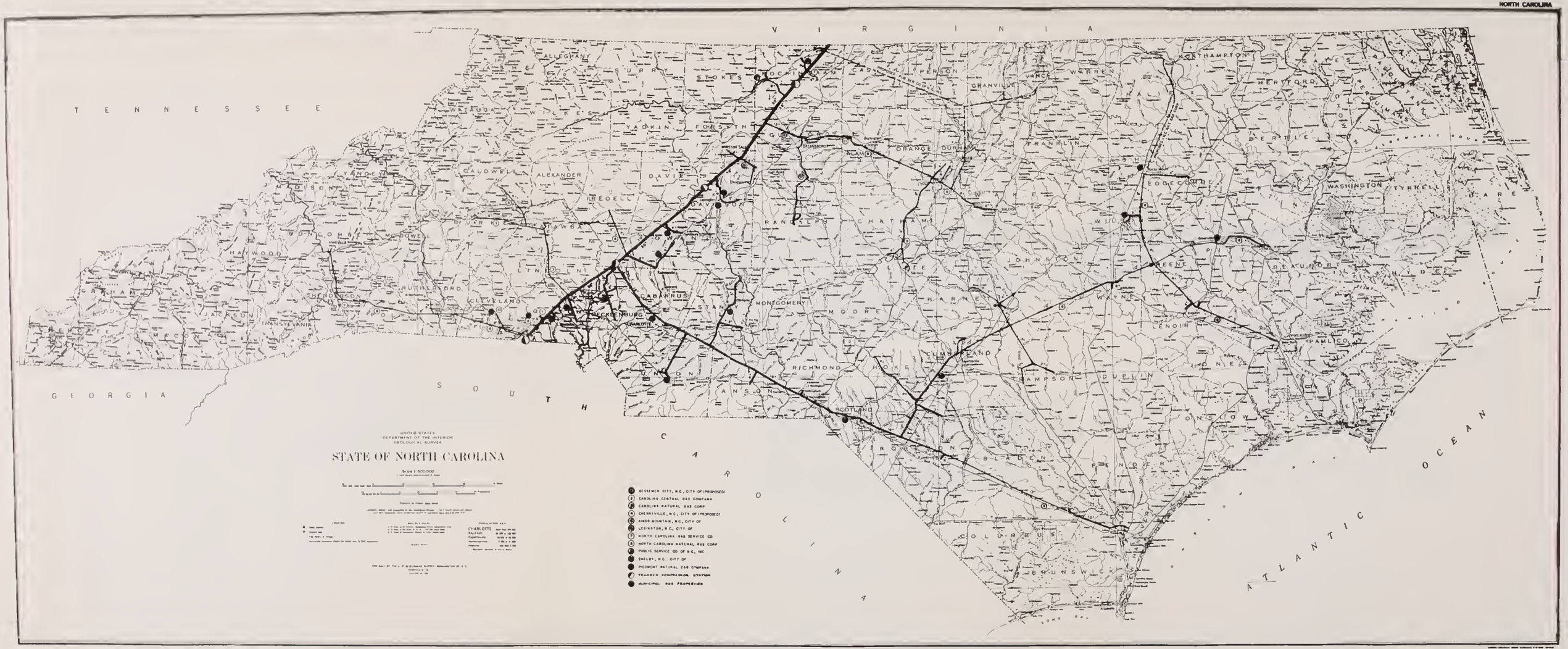
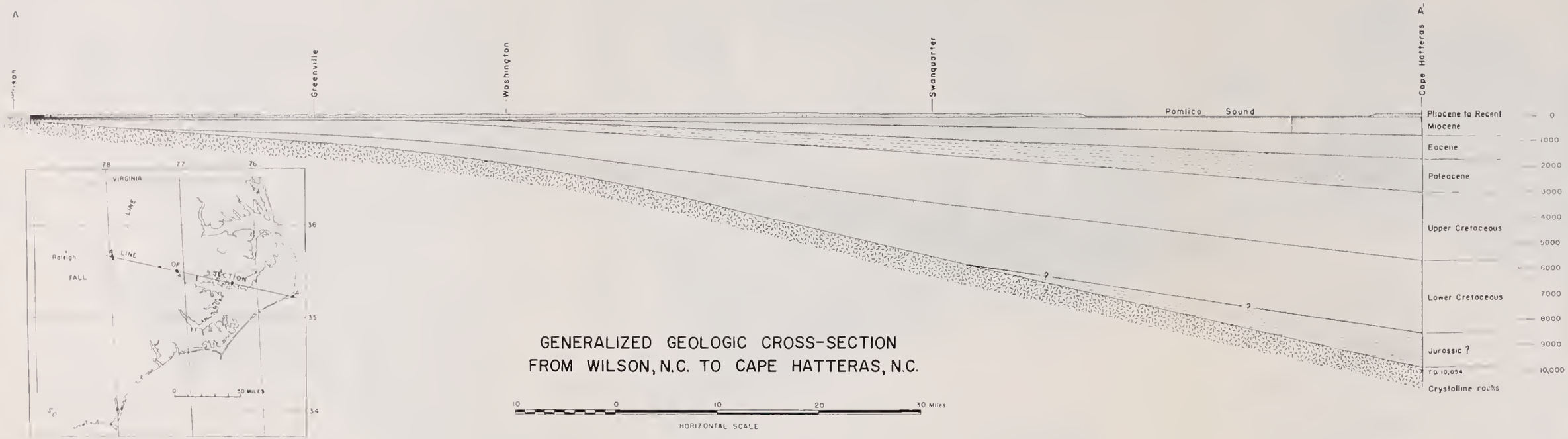
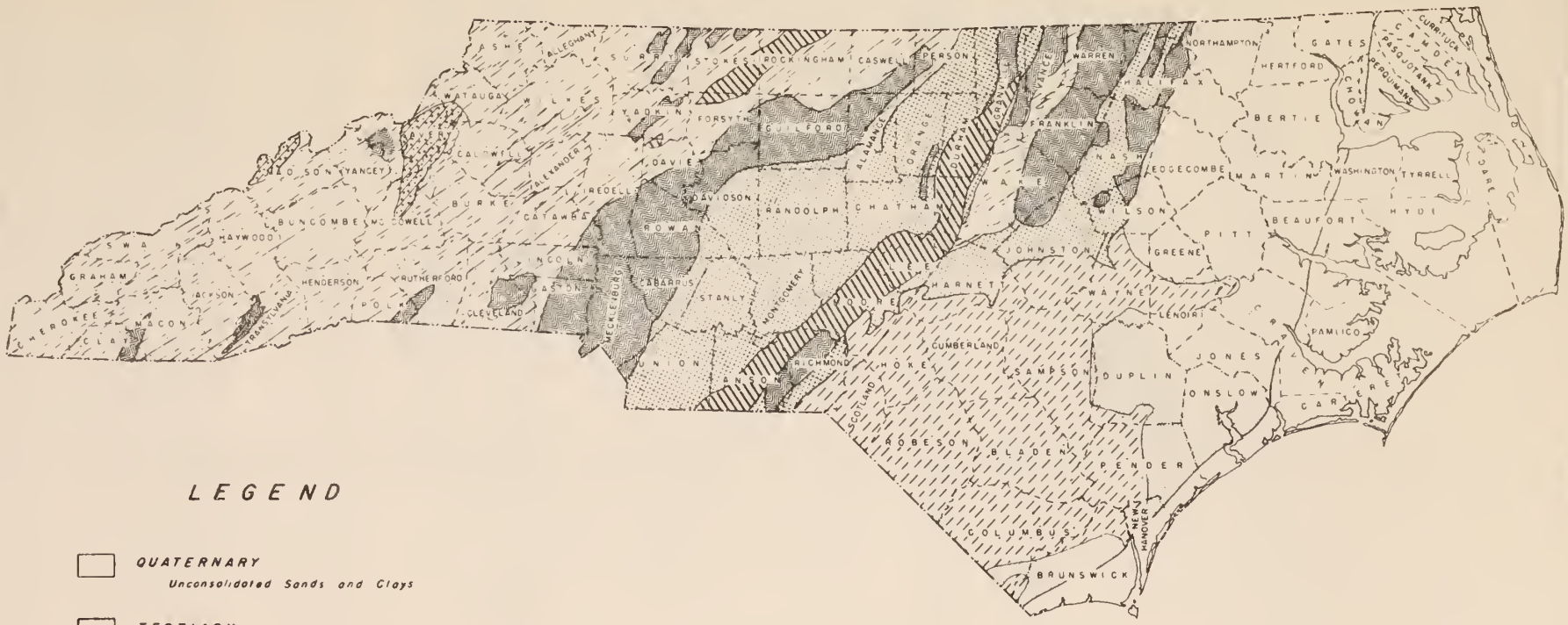

NORTH CAROLINA
VIRGINIA
TENNESSEE
GEORGIA
SOUTH CAROLINA
ATLANTIC OCEAN
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
STATE OF NORTH CAROLINA
GESSNER CITY, N.C., CITY OF (PROPOSED)
CAROLINA CENTRAL GAS COMPANY
CAROLINA NATURAL GAS CORP
CHERRYVILLE, N.C., CITY OF (PROPOSED)
HIGGS MOUNTAIN, N.C., CITY OF
LEXINGTON, N.C., CITY OF
NORTH CAROLINA GAS SERVICE CO
NORTH CAROLINA NATURAL GAS CORP
PUBLIC SERVICE CO OF N.C., INC
SHELBY, N.C. CITY OF
PIEDMONT NATURAL GAS COMPANY
TRANSCO COMPRESSOR STATION
MUNICIPAL GAS PROPERTIES
CHARLOTTE
RALEIGH
FAYETTEVILLE
WINSTON-SALEM
GREENSBORO
DURHAM
ALAMANCE
ORANGE
CHATHAM
RANDOLPH
DAVIDSON
ROWAN
CABARRUS
MECKLENBURG
CHARLOTTE
STANLY
MONTGOMERY
MOORE
RICHMOND
ANSON
UNION
SCOTLAND
HOKE
CUMBERLAND
HARNETT
JOHNSTON
WAYNE
LENOIR
GREENE
PITT
WILSON
NASH
EDGECOMBE
WASHINGTON
TYRRELL
DARE
BEAUFORT
PAMLICO
JONES
ONSLOW
CARTERET
SAMPSON
DUPLIN
PENDER
BLADEN
ROBESON
COLUMBUS
BRUNSWICK
HANOVER
NORTHAMPTON
HERTFORD
BERTIE
GRANVILLE
VANCE
WARREN
FRANKLIN
PERSON
STOKES
ROCKINGHAM
SURRY
YADKIN
FORSYTH
GUILFORD
DAVIE
IREDELL
ALEXANDER
CALDWELL
WATAUGA
WILKES
AVERY
YANCEY
MADISON
BUNCOMBE
MCDOWELL
BURKE
CATAWBA
LINCOLN
RUTHERFORD
CLEVELAND
HENDERSON
TRANSYLVANIA
HAYWOOD
GRAHAM
JACKSON
MACON
CHEROKEE
CLAY
ALLEGHANY
ASHE
CASWELL
LONG BAY
NORTH CAROLINA

Figure 73.



GENERALIZED GEOLOGIC CROSS-SECTION
FROM WILSON, N.C. TO CAPE HATTERAS, N.C.

Figure 74



LEGEND

QUATERNARY
Unconsolidated Sands and Clays

TERTIARY
Clays, Sands and Marls

CRETACEOUS
Sands, Clays and Marls

TRIASSIC
Sandstones and Shales

CARBONIFEROUS
Principally Granite and Diorite

CAMBRIAN
Quartzite, Slate, Shale and Limestone

VOLCANIC SLATE SERIES (Lower Paleozoic?)
Interbedded Slates, Flows, Tuffs and Breccias

PRE CAMBRIAN
Gneisses and Schists

GENERALIZED GEOLOGIC MAP OF NORTH CAROLINA

Scale
0 25 50 100
MILES

The column is as follows:

Quaternary:	Pleistocene sands and clays.
Tertiary:	Yorktown Formation (Miocene) Castle Hayne Limestone (Eocene) Beaufort Formation (Paleocene) not exposed and not present west of Meridian 77 and south of the center of Pamlico Sound.
Upper Cretaceous:	Pee Dee Formation Black Creek Formation Tuscaloosa Formation
Lower Cretaceous:	Not divided into formations, not exposed.
Triassic:	Not divided into formations, not exposed. Probably limited to the northern and eastern half of the Coastal Plain.

The formations in the eastern half of the Coastal Plain are good water-producing formations to depths of 500 to 600 feet. However, in the tidewater section, as far west as the heads of the sounds and estuaries, salt water is often encountered at depths of 200 to 400 feet.

There are no storage projects for natural gas in North Carolina. The possibility of storing natural gas in North Carolina will depend upon finding a suitable area.

There are no regulations affecting the storage of natural gas in North Carolina.

NORTH DAKOTA

Miller Hanson
Assistant State Geologist
North Dakota Geological Survey

Abstract

North Dakota has no underground storage for natural gas. Limited underground storage for LP gas is presently available in caverns dissolved in salt beds at Williston. More salt caverns can probably be developed over large areas of the western part of the state.

Any projects involving excavation of caverns in Tertiary or Cretaceous rocks for storage of natural gas in North Dakota would probably require artificial support of cavern roofs and perhaps lining of the entire cavern.

Future planning will probably include storage in some of North Dakota's smaller oil field structures as these fields approach depletion.

Introduction

Natural gas from the Cedar Creek and Little Missouri Fields in Bowman County, North Dakota, is produced from the Cretaceous Eagle Sandstone. The only other commercial source in the state is solution gas from fields on the Nesson Anticline. The Madison Formation is the source of most of this gas which is treated at the Tioga Gasoline Plant of the Signal Oil and Gas Company. The Montana Dakota Utilities Company distributes the Tioga gas, sending some west to storage in Montana during the season of low demand. The same company distributes the Bowman County gas, but here production is curtailed when demand is low.

Large reserves of gas in Silurian rocks on the Nesson Anticline may be brought into production at any time. Nineteen wells, now shut-in, are capable of producing from the Silurian condensate reservoir.

At the present time, there are no facilities in North Dakota for underground storage of natural gas.

Potential Development of Underground Natural Gas Storage Facilities

Excavated Storage Caverns

A generalized east-west cross section of North Dakota (figure 76) shows the surface consists of Cretaceous rocks in the east and Tertiary rocks in the west. Also shown on the cross section are the glacial deposits which vary in thickness from a featheredge to about 200 feet. In glacial channels thicknesses of 500 feet have been encountered. Glacial deposits cover most of the surface of North Dakota except for the southwest corner of the state.

In considering excavated chambers for natural gas storage in Tertiary rocks, it is improbable that ideal conditions of an impervious zone for the storage chamber with a competent rock for the roof will be found. The Tertiary rocks are commonly poorly indurated, thin beds of sand and clay with zones of concretions and a few layers of argillaceous limestone or sandstone which are generally fractured. Although some satisfactory locations may be determined by test borings, roof support and perhaps lining of the entire storage cavity would be required in most areas.

Excavated chambers in the Cretaceous Pierre shale in North Dakota would probably require roof support. Under most conditions they probably would not require lining, since the Pierre shale is practically impervious. Fractured zones in the Pierre Formation, known from ground water studies, present a potential leakage problem in some areas.

The Pierre shale is light bluish gray to medium gray and for the most part poorly indurated. Specimens from outcrops, especially when wet, can readily be scored with the fingernail. There are limey zones and siliceous zones in the Pierre that are considerably harder, but they are generally few, thin, and discontinuous and cannot be depended upon for cavern roof support. A test boring program should be included in any investigation of cavern excavation in the Pierre shale for natural gas storage. There are several places in eastern North Dakota where the Pierre Formation has little or no glacial drift overlying it. Pierre shale outcrops near Devils Lake, Jamestown, and Valley City might be advantageous sites for natural gas storage caverns. At numerous other localities in the central and eastern parts of the state glacial deposits and bed rock above the Pierre shale would require much deeper shafts to the caverns.

Storage in Partially Depleted Gas Fields

As mentioned above there are only two natural gas fields in North Dakota, both in Bowman County. It would seem reasonable to assume that these could be used for storage of natural gas, and that the available storage might approach the figure of 16 million Mcf, the estimated amount of gas already produced from the fields. However, sufficient storage capacity is available in adjacent fields in Montana and, due to low porosity of the producing formation and poor permeability, the North Dakota fields are not considered favorably as potential storage reservoirs.

Solution Caverns in Salt Deposits

Storage of LP gas in North Dakota has been pioneered by the Dakota Salt and Chemical Company at Williston. At their plant, salt is mined hydraulically through two well bores. The salt bed is 200 feet thick and lies at a depth of about 8,000 feet. This is the Mississippian "A" salt of Anderson and Hansen (1957).

The volume of the cavity in the first well, which already has LP gas in storage, is now estimated at 90,000 barrels. The second well has 60,000 barrels of storage capacity, and a total storage capacity of 250,000 barrels is expected to be available by the summer of 1961. Natural gas can be stored in similar cavities if engineering and economic conditions are considered favorable.

In addition to the Mississippian "A" salt there are several other salt layers at various depths which might be utilized for solution caverns. Anderson and Hansen (1957) prepared a comprehensive report on halite deposits in North Dakota in which they presented maps of eleven different salt beds. Of these, several are more than 50 feet thick in various parts of North Dakota. The major salt beds in the section are shown in figure 77. The Triassic "A" salt is 100 feet thick in Dunn County. The Triassic "B" salt is 150 feet thick in western Stark County and adjoining areas. Both Triassic salt beds lie at depths of about 7,000

NORTH DAKOTA STRATIGRAPHIC COLUMN

SYSTEMS	GROUPS	ROCK UNITS	LITHOLOGY	THICKNESS	DESCRIPTION
TERTIARY		PLEISTOCENE		0-500'	Morainal, delta, and outwash deposits, lake beds and valley fill.
		WHITE RIVER fm		0-200'	Limestone, freshwater, clay, calcareous, sandstone beds, and conglomerates.
		GOLDEN VALLEY fm		0-200'	Clay, sandy, kaolinitic, white, shale, carbonaceous, grey; fine sandstone and siltstone.
	FORT UNION GROUP	TONGUE RIVER fm		0-1100'	Shale, calcareous, light to dark colored, lignite and sandstone. Contains most of the known reserves of lignite in North Dakota.
		LUDLOW & CANNONBALL fm		0-250' 0-360'	Ludlow formation: Lignite, shale and sandstone. Cannonball formation: Marine sands, sandstone, clays and shales.
CRETACEOUS		HELLCREEK fm		0-575'	Sandstone, shale, clay, bentonitic, lignite, thin bedded.
	MONTANA GROUP	FOX HILLS fm		0-320'	Sandstone, brown to grey; ironstone concretions.
		PIERRE fm		0-2300'	Shale, light to medium gray, ironstone concretions. Contains two fine grained silty sands in the southwestern part of the state; the Eagle and Judith River. The Eagle produces gas in Cedar Creek gas field.
		JUDITH RIVER			
		EAGLE			
	COLORADO GROUP	NIOBRARA fm		0-200'	Shale, calcareous, medium light gray to medium gray; contains calcareous "white specks"; known in Canada as the "First White Specks".
		CARLILE fm		0-410'	Shale, medium dark grey to dark grey.
		GREENHORN fm		0-150'	Shale, calcareous, soft, dark gray, limestone, shaly, thin bedded. Contains Inoceramus fragments and Globigerina. Contains calcareous "white specks". Known in Canada as the "Second White Specks". Good electric and radioactivity log marker.
		BELLE FOURCHE fm		0-350'	Shale, micaceous, medium dark gray to dark gray, bentonite, white to light blue gray. Base of the Belle Fourche picked on electric and radioactivity log markers.
	DAKOTA GROUP	MOWRY fm		0-180'	Shale, flaky, soft, medium grey to dark gray, bentonitic, bentonite, white to light blue grey.
		NEWCASTLE SS		0-150'	Sandstone, quartzose, silty and shaly, light gray.
		SKULL CREEK fm		0-140'	Shale, soft, medium to dark gray.
		FALL RIVER fm		0-210'	Sandstone, fine to coarse, quartzose, light gray, shale, silty, lumpy, gray.
		LAKOTA fm		0-110'	Sandstone, medium to coarse, angular to subrounded, quartzose. Often contains light brown iron carbonate siltstone spherulites (pellets) and gray shale streaks.
JURASSIC		MORRISON fm		0-260'	Shale, non marine, gray to greenish, occasionally contains small amounts of coal.
		SUNDANCE fm		0-850'	Shale, green, gray to brown, sandstone, fine grained, glauconitic, occasional limestone.
		PIPER fm		0-350'	Limestone, dense, yellow gray, anhydrite, shale, gray to brown.

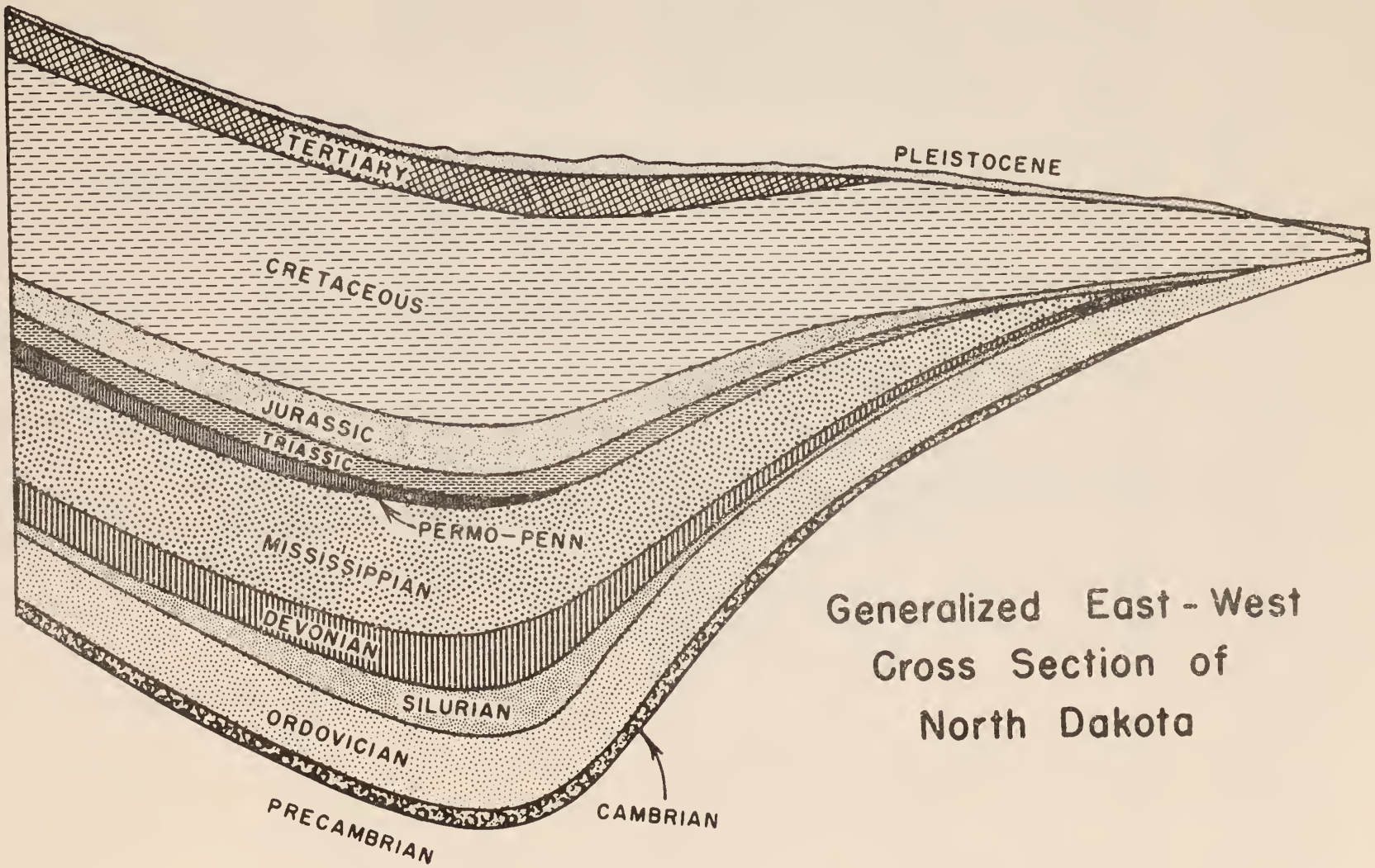

TERTIARY
PLEISTOCENE
CRETACEOUS
JURASSIC
TRIASSIC
PERMO-PENN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
PRECAMBRIAN
CAMBRIAN
Generalized East - West
Cross Section of
North Dakota

Figure 76

TRIASSIC		SPEARFISH fm "UNRESTRICTED"	S S	0-730'	Siltstone, moderate to light brownish and reddish brown, sandstone, reddish, brownish, orange to white; halite, gypsum and anhydrite. Produces oil from basal sandstone in Newburg and South Westhope fields, in Bottineau County.
PERMIAN		MINNEKAHTA fm		0-40'	Dolomite and limestone, dense, pink to purple.
		OPECHE fm	S	0-510'	Shale and silt, reddish; halite and anhydrite.
PENN.		MINNELUSA fm		0-275'	Sandstone, reddish to whitish, small amounts of shale and dolomite.
		AMSDEN fm		0-200'	Dolomite, pinkish to light purple, shale, gray to brownish.
MISSISSIPPIAN	BIG SNOWY GROUP	HEATH & OTTER fms		0-300'	Heath formation: Shale, carbonaceous, gray to greenish, sandstone, fine to medium grained, light brownish to white. Sandstone produces oil in Fryburg, Rocky Ridge and Dickinson Heath pools.
				0-250'	Otter formation: Shale, grey, greenish and brown, limestone, thin interbedded.
		KIBBEY fm		0-250'	Siltstone and shale, reddish, limestone, dense, light colored, sandstone, fine to medium grained, rounded, reddish. The limestone is an excellent marker on electric and radioactivity logs.
	MADISON GROUP	POPLAR INTERVAL	S S	0-600'	Evaporites, halite and anhydrite, shale and mudstones, iron stained, limestone beds, thin alternating. This interval contains most of the halite of the Madison group.
		RATCLIFFE INTERVAL	S	0-250'	Limestone, largely oolitic, pale yellow brown; dolomite, dense, mudstone and evaporites. Contains the lower Madison salt bed in the central part of the basin referred to as the "last salt". Produces oil in Burke and Bottineau Counties.
		MADISON UNDIFF. — FROBISHER ALIDA INTERVAL		0-585'	Limestone, fine grained, fragmental to oolitic pale yellow brown to pinkish; evaporites. Becomes increasingly evaporitic toward the east side of the basin. Produces oil in Bottineau, Renville and Burke Counties.
		TILSTON INTERVAL		0-230'	Limestone, fragmental to oolitic, pale yellow brown to pinkish, anhydrite, small gray shale. Produces oil in the North Souris and Roth fields of Bottineau County.
		BOTTINEAU INTERVAL		0-630'	Limestone, fragmental to argillaceous fine grained dense, dark gray to brown becoming sometimes pale orange to pinkish and containing occasional oolitic beds along the east flank of the basin. Often cherty near the base.

The terms Bottineau, Tilston, Frobisher-Alida, Ratcliffe and Poplar are terms for intervals between markers on radioactivity and electric logs. Bottineau, Tilston and Frobisher-Alida intervals are not carried into the central part of the basin.

Madison Undifferentiated: Term used in the central part of the basin where the radioactivity and electric log markers used for correlation on the east side of the basin are not present.
Limestone, fine grained, autrosic to sublithographic dense, fragmental, and some oolitic, brownish gray, pale yellow brown, light to medium gray, some dolomite. Oil and gas are produced from near the top of this section in fields on the Nesson Anticline.

		BAKKEN fm		0-110'	Shale, carbonaceous, dark gray, sandstone, fine grained, siltstone, light grey, limestone, grey.
DEVONIAN — UPPER DEVONIAN		THREE FORKS fm		0-240'	Siltstone, grayish red to grayish orange; shale, interbedded greenish gray, reddish, dolomitic, dolomite, anhydrite, white. Erratic sandstone produces oil in Antelope field in McKenzie County.
		BIRDBEAR fm		0-125'	Limestone, crystalline, porous, yellowish to dark brown grey, anhydrite, brownish to medium grey.
		DUPEROW fm		0-460'	Limestone, crystalline, to granular, light brown gray to brown gray, dolomite, crystalline, brown gray; anhydrite, anhydritic limestone and dolomite, white to brownish gray; shale, medium to dark gray. Produces oil in Beaver Lodge field.
DEVONIAN — MIDDLE DEVONIAN		SOURIS RIVER fm		0-300'	Dolomite and limestone, crystalline to dense, light to dark gray and brownish gray, siltstone, light to medium gray, anhydrite, white, brownish gray to medium dark grey.
		DAWSON BAY fm		0-185'	Dolomite and limestone, crystalline, argillaceous, light gray, brownish gray, to pinkish gray.
		PRAIRIE fm	S	0-500'	Evaporites; halite and some anhydrite.
		WINNIPEGOSIS fm		0-400'	Limestone, shaly, gray, limestone and dolomite, fragmental, granular and fine grained, brownish to pinkish gray.
		ASHERN		0-75'	Dolomite, shaly, shale, dolomitic, red to pale orange; anhydrite, inclusions, white.
SILURIAN		INTERLAKE fm.		0-1200'	Dolomite, granular to lithographic, white and pale orange to pinkish. Produced oil in Beaver Lodge field, wells currently shut in due to high gas-oil ratio. Stonewall is indistinguishable from the interlake in the subsurface.
SILURO - ORD.		STONEWALL fm			
ORDOVICIAN	BIG HORN GROUP	STONY MTN fm		0-200'	Dolomite, granular, light colored; limestone, argillaceous, fossiliferous, grey; shale
		RED RIVER fm		0-700'	Limestone, granular to dense, yellow gray, brownish gray, medium dark grey to brownish black, dolomite, similar to the limestone in appearance, little anhydrite. Good porosity in upper part. Produces oil in Little Missouri field and did produce in Writing Rock field. Good shows in Beaver Lodge field, tested 150 B.O.P.D. and 5,069,000 C.F.G.P.D.
		WINNIPEG fm		0-334'	Shale, waxy, green to gray, sandstone, fine to medium grained, rounded to angular, quartzose, friable, poorly cemented to well cemented with pyrite and silica.
CAMBRO - ORD.		DEADWOOD fm		0-1000'	Limestone, fragmental, light to medium light gray, dolomite, fragmental, light to medium light gray, sandstone fine to medium grained, rounded to subrounded, glauconitic, shale, gray to greenish. No commercial production but shows have been reported.
PRECAMBRIAN					

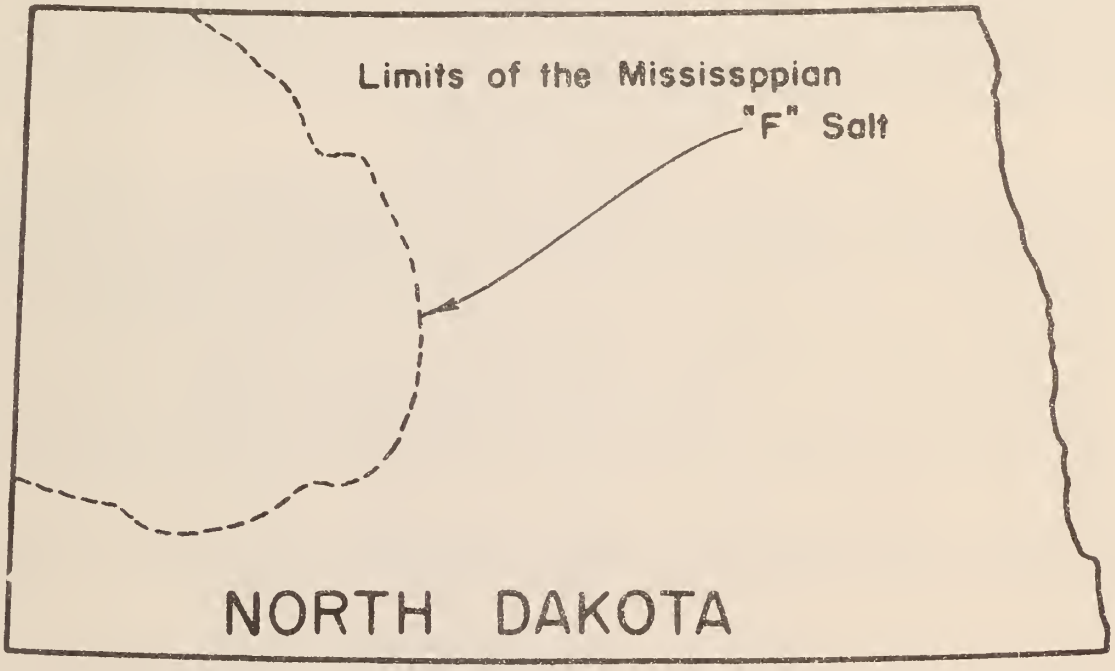
by S.B. Anderson, and W. P. Eastwood

S Major salt beds in Triassic, Permian, Mississippian, and Devonian rocks.

Figure 77.

feet. The Mississippian "X" salt is 30 feet thick at a depth of less than 5,000 feet a few miles east of Minot near the Ward County line. In western Bottineau County the Devonian salt is 150 feet thick at a depth of 6,090 feet. In many of these areas salt caverns for storage of natural gas can be developed similar to those of the Williston LP gas storage project. Figure 78 shows the approximate limits of one of the more extensive salt beds.

Natural gas storage may prove to be feasible in some of the state's oil fields as they approach depletion. The smaller oil field structures may well be utilized for natural gas storage when the need for such storage reaches a critical point.



General area underlain by salt deposits

Figure 78.

Reference

Anderson, S. B. and Hansen, D. E. (1957), Halite deposits in North Dakota, North Dakota Geol. Survey Rept. Inv. no. 28.

OHIO

Ralph J. Bernhagen, Division Chief
Division of Geological Survey

Introduction

At one time the natural gas supply in Ohio was adequate to take care of the total domestic and industrial demand. However, gas consumption increased so rapidly that it has been many years since the native source has been able to meet the demand. As early as 1907 it became necessary to import gas from West Virginia in order to assure an adequate supply in certain areas. The demand has continued to increase, and today over 95% of our annual consumption is imported.

The underground storage facilities have played an important role in the development of Ohio in that they have assured a dependable and constant supply of gas to domestic, commercial and industrial consumers on a year-round basis. Without the 16 underground storage areas (figure 79) it would have been impossible to meet the peak demand loads during the winter months.

This is a reflection on the leadership, vision and ingenuity of the gas industry, for as a result of its initiative Ohio has an adequate gas supply.

Gas Production in Ohio

The first commercial use of natural gas in Ohio began at Findlay in 1884. The first well was completed in the Trenton Limestone in November of that year. This created a tremendous wave of drilling activity which in turn discovered vast reservoirs of natural gas which were far beyond the needs of local domestic consumption. In 1886 many industries were formed, and others were induced to move to this new source of cheap fuel. The population of Findlay increased from a few thousand to 25,000 in two years. It was believed that the supply of natural gas was inexhaustible, and as a result many millions of cubic feet were wastefully lost to the air or burned as flares. This period of plenty was short-lived, for during the winter of 1888 and 1889 the supply diminished, and many of the manufacturing plants were forced to shut down or curtail their operations so that the citizens would have sufficient gas to heat their homes. Fortunately this deficiency was only temporary as lines were laid and new wells were found slightly more distant from Findlay.

The excitement caused by the discovery of natural gas at Findlay spread rapidly over Ohio. Although natural gas had been previously known to exist in many areas over the state, it was not until the Findlay development that its economic value was fully appreciated.

The first step toward testing the rocks in central Ohio began near Lancaster on December 2, 1885, when the Lancaster Natural Gas Company was incorporated. The first well, situated near the Hocking Valley station, was completed February 1, 1887. It had penetrated the Clinton sand at a depth of 1,957 feet and encountered a small amount of gas. Subsequent drilling produced large volumes which soon greatly exceeded the demand in the city, and the boom spectacle enveloped Lancaster as it had Findlay.

The wells at Lancaster tapped the vast Clinton sand gas belt, one of the greatest natural gas reservoirs ever developed. The field, nearly continuous, stretches along an axis from near Oak Hill in southern Jackson County to Lakewood on Lake Erie in Cuyahoga County. More than 50,000 wells have been drilled, 70% of which have been productive. Although recovery from the Clinton sand has passed its peak, it is still the largest gas producer in Ohio.

It is estimated that there have been some 175,000 wells drilled in Ohio in the search for oil and gas. Approximately 10,000 miles of transmission pipelines (figure 80) have been laid, forming a vast interlocking network to transport and assure a uniform gas supply to consumers (table 28).

Stratigraphy

Figure 81, a generalized section of the rocks of Ohio, shows the stratigraphic relations of the numerous producing horizons. The terms commonly used by the well drillers are correlated with the proper geologic name.

The Trenton Limestone (Lower Ordovician) was the first prolific gas producing formation in Ohio. The underlying Cambrian System has not been tested sufficiently to determine its potential. However, in recent months, both oil and gas in commercial quantities have been discovered in rocks of this system.

The Clinton sand is the great gas bearing stratum of Ohio. It ranges in depth from 2000 to 8000 feet and has been penetrated by an estimated 50,000 wells, 70% of which have been productive.

Besides the Trenton Limestone and the Clinton sand, Ohio has many so-called shallow sands present in the eastern and southeastern portion of the state which have produced large quantities of natural gas. The most widespread and prolific of these are the Newburg, Oriskany, Berea, Big Injun, Keener, and the First and Second Cow Run. Others which have produced lesser amounts are the Gordon, Weir, Squaw, Maxton, First Salt, Macksburg 500-Foot, Macksburg 300-Foot, Buell Run, Peeker, Vincent, Wolf Creek, Mitchell, and Goose Run.

Gas Storage Projects

As of January 1, 1960, 16 gas storage areas were in operation in Ohio of which 13 used the Clinton sand, two used the Oriskany sand, and one the Second Berea sand. The combined storage area involves 378,000 acres and 2,198 wells. See table 29 for natural gas underground storage areas in Ohio.

Possibilities of Expansion

In view of the fact that the Clinton sand has proven to be the most satisfactory medium for gas storage, there is no question that future expansion of storage facilities will continue to use this formation. As existing producing pools become exhausted, more and more areas will become available for conversion into storage. The "Clinton belt" as shown on the oil and gas fields map (figure 82) will ultimately become a storage area to meet future demands.

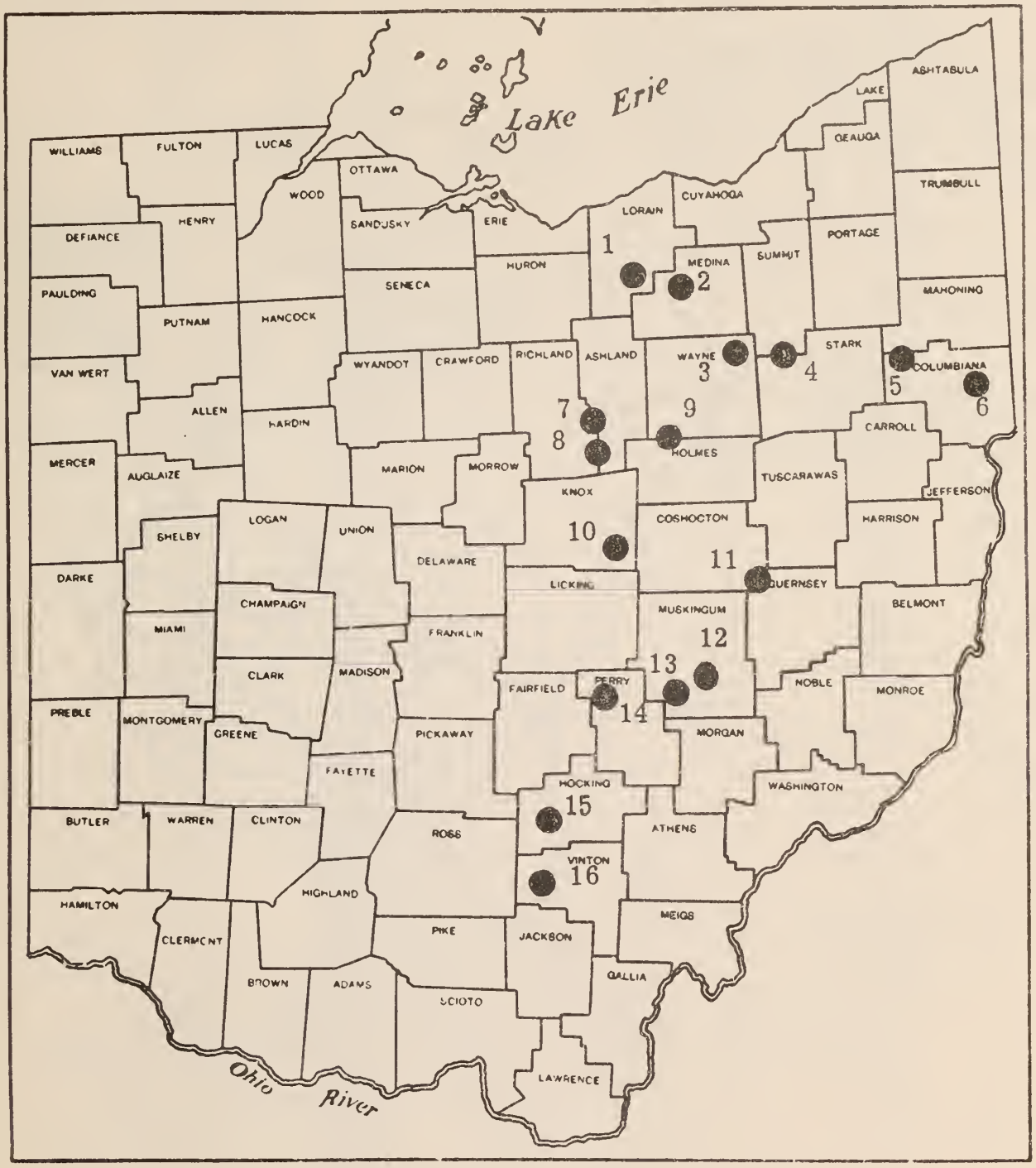
Table 28.– GAS PRODUCTION IN OHIO

(THOUSANDS OF CUBIC FEET)

Year	Production	Year	Production	Year	Production	Year	Production
1800--1875	-	1900	13,926,400	1925	43,235,000	1950	43,163,000
1876	-	1901	13,728,000	1926	47,363,000	1951	38,879,000
1877	-	1902	15,059,200	1927	51,381,000	1952	30,993,000
1878	-	1903	28,636,800	1928	56,341,000	1953	37,542,000
1879	-	1904	33,987,200	1929	57,936,000	1954	28,824,000
1880	-	1905	36,579,200	1930	63,391,000	1955	33,756,000
1881	-	1906	45,436,020	1931	56,326,000	1956	25,368,000
1882	-	1907	52,040,996	1932	51,166,000	1957	30,384,000
1883	-	1908	47,442,393	1933	47,929,000	1958	33,875,000
1884	-	1909	53,222,619	1934	50,330,000	1959	36,340,000
1885	640,000	1910	48,232,406	1935	49,592,000		
1886	2,556,800	1911	49,149,749	1936	46,994,000		TOTAL
1887	6,393,600	1912	56,210,052	1937	42,783,000		
1888	9,590,400	1913	50,612,211	1938	35,257,000		2,992,496,422
1889	33,350,400	1914	68,270,174	1939	36,469,000		mcf
1890	29,948,800	1915	79,510,032	1940	40,639,000		
1891	19,667,200	1916	69,888,070	1941	41,858,000		
1892	13,657,600	1917	68,917,231	1942	45,055,000		
1893	9,657,600	1918	61,261,069	1943	52,001,000		
1894	8,160,000	1919	63,153,100	1944	51,724,000		
1895	8,028,800	1920	58,938,000	1945	49,967,000		
1896	7,494,400	1921	47,412,000	1946	61,570,000		
1897	7,488,000	1922	51,181,000	1947	68,946,000		
1898	9,516,800	1923	53,812,000	1948	65,619,000		
1899	11,932,800	1924	47,396,000	1949	46,512,000		

Table 29- Natural Gas Underground Storage Areas in Ohio

County	Township	Company	Storage Name	Date	Rock Type	Geol. Sys.	Form or Group	Capacities	Depth	Development
1 Medina Lorain	Litchfield Spencer Lagrange Pittsfield Wellington Huntington Penfield Grafton	Ohio Fuel Gas	Wellington	1947	SS	Sil.	"Clinton Sd."	21,400 MMCF @1150 PSI	2500'	Depleted Gas Pool
2 Medina	Lafayette York Medina - (Boardman)	Ohio Fuel Gas	Medina	1958	SS	Sil.	"Clinton Sd."	8,500 MMCF @1150 PSI	3050'	Depleted Gas Pool
3 Wayne	Chippewa	East Ohio Gas	Chippewa	Nov. 1951	SS	Sil.	"Clinton Sd."	8,235 MMCF @1400 PSI	3600'	Depleted Gas Pool
4 Summit Stark	Franklin Green Lawrence Jackson Plain	East Ohio Gas	Stark-Summit	Aug. 1941	SS	Sil.	"Clinton Sd."	118,065 MMCF @1300 PSI	4200'	Depleted Gas Pool
5 Columbiana	Knox Butler	East Ohio Gas	Columbiana	May 1950	SS	Dev.	Oriskany	3,050 MMCF @1300 PSI	3550'	Depleted Gas Pool
6 Columbiana	Salem Fairfield Elk Run Center	Manufacturers' Light & Heat	Brinker	Nov. 1940	SS	Miss.	"Sec. Berea Sd."	7,000 MMCF @ 280 PSI	800'	Depleted Gas Pool
7 Ashland	Mifflin Vermillion	Ohio Fuel Gas	Pavonia	1951	SS	Sil.	"Clinton Sd."	38,000 MMCF @1150 PSI	2500'	Depleted Gas Pool
8 Ashland Richland	Vermillion Mifflin Green Hanover Worthington Monroe	Ohio Fuel Gas	Weaver	1936	SS	Sil.	"Clinton Sd."	71,500 MMCF @1150 PSI	2500'	Depleted Gas Pool
9 Holmes Wayne	Ripley Washington Clinton	Ohio Fuel Gas	Holmes	1953	SS	Sil.	"Clinton Sd."	24,500 MMCF @1150 PSI	3200'	Depleted Gas Pool
10 Knox	Butler	Ohio Fuel Gas	Knox	1945	SS	Sil.	"Clinton Sd."	3,700 MMCF @ 950 PSI	2900'	Depleted Gas Pool
11 Guernsey Coshocton	Wheeling Knox Liberty Linton	Ohio Fuel Gas	Guernsey	1954	SS	Dev.	Oriskany	5,500 MMCF @1150 PSI	3500'	Depleted Gas Pool
12 Muskingum	Salt Creek	Ohio Fuel Gas	Zane	1955	SS	Sil.	"Clinton Sd."	80 MMCF @1100 PSI	4000'	Depleted Gas Pool
13 Muskingum	Brush Creek Newton	Nat. Gas & Oil	Longshore	May 1954	SS	Sil.	"Clinton Sd."	7,000 MMCF @1000 PSI	3850'	Depleted Gas Pool
14 Perry	Hopewell Thorn Reading	Nat. Gas & Oil	Pitkin	June 1956	SS	Sil.	"Clinton Sd."	1,500 MMCF @1000 PSI	2800'	Depleted Gas Pool
15 Hocking	Laurel Benton Perry Salt Creek Washington	Ohio Fuel Gas	Benton	1936	SS	Sil.	"Clinton Sd."	39,000 MMCF @ 780 PSI	1950'	Depleted Gas Pool
16 Vinton	Richland Harrison	Ohio Fuel Gas	McArthur	1957	SS	Sil.	"Clinton Sd."	10,500 MMCF @ 900 PSI	2000'	Depleted Gas Pool



GAS STORAGE AREAS, 1960

Figure 79.

Ohio's Principal
NATURAL GAS PIPELINES

December, 1959

LEGEND
New Lines _____
Lines Removed xxxx

Figure 80

Published by the
OHIO DIVISION OF GEOLOGICAL SURVEY

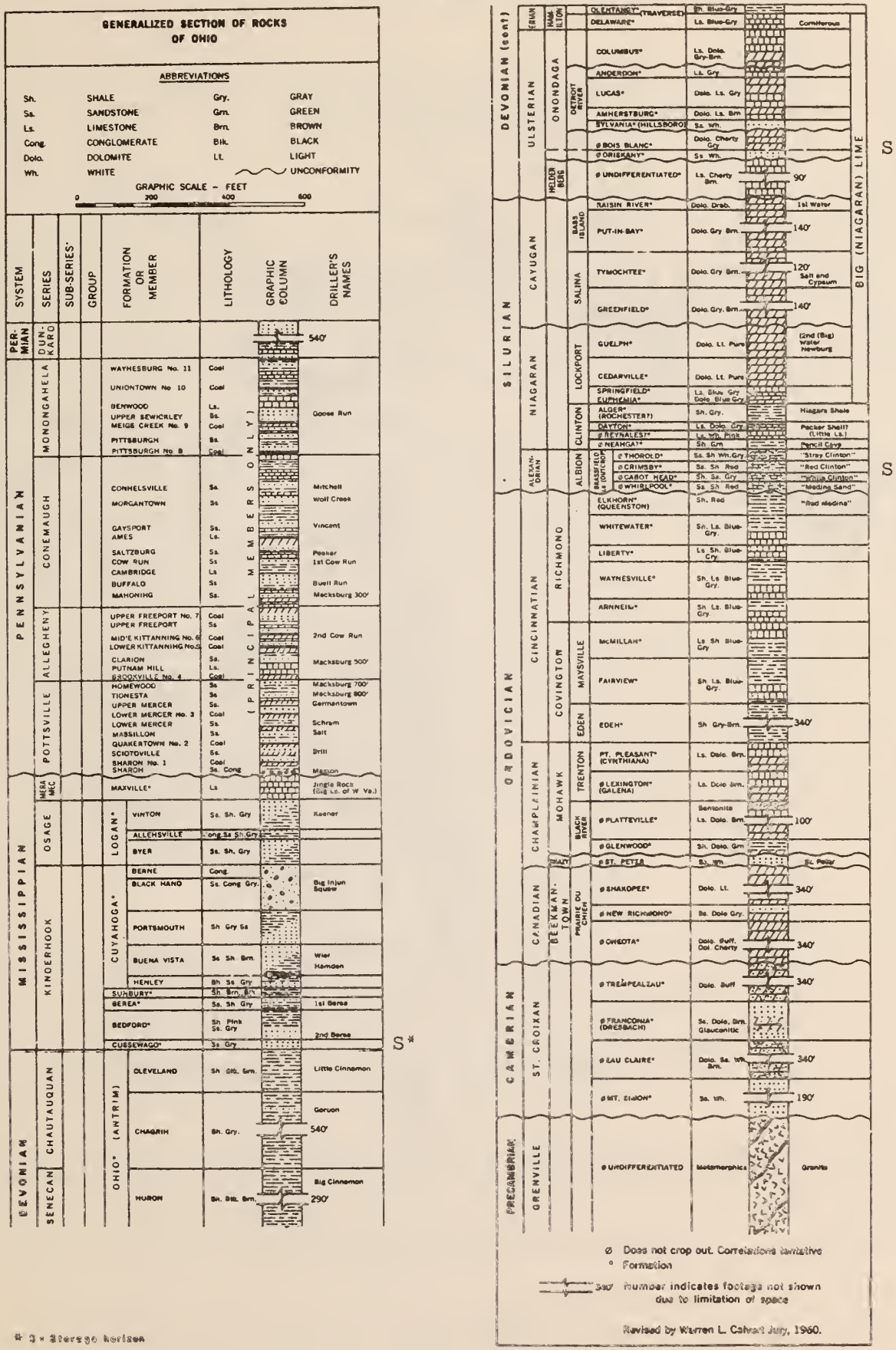
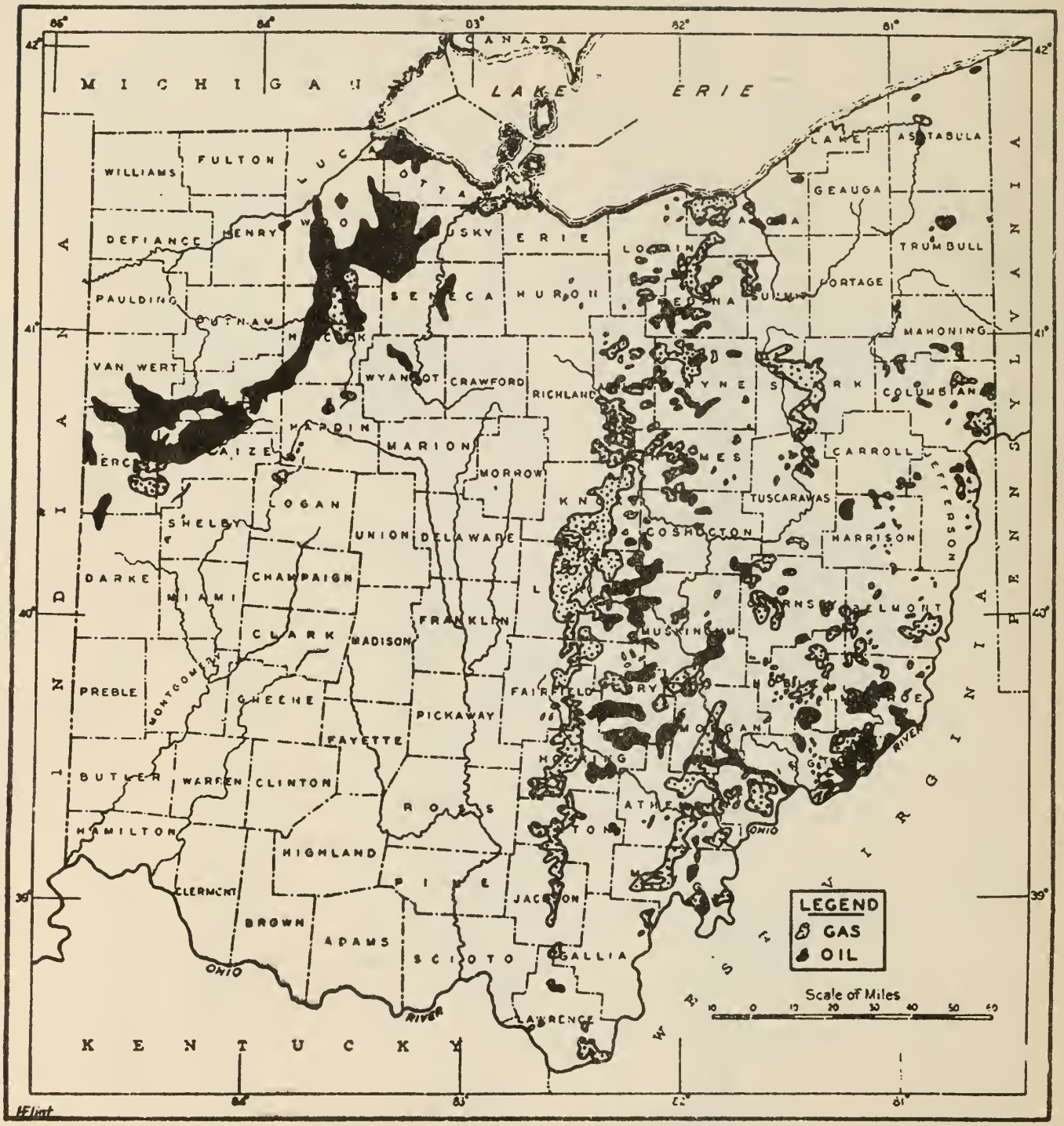


Figure 81.



OIL AND GAS FIELDS OF OHIO

Figure 82.

OKLAHOMA

Louise Jordan, Geologist
Oklahoma Geological Survey

General Remarks

Oklahoma in 1960 ranked third in the nation in marketed output of natural gas, according to preliminary figures of the U. S. Bureau of Mines. Marketed production amounted to 898,008,000 Mcf, an increase of 11% over that of 1959. Production was reported from 65 of the 77 counties of the state, with Texas, Garvin, Beaver, Harper, and Grady Counties leading in that order. At year-end proved recoverable reserves were estimated at 17,300,000,000 Mcf. Of this figure 12,300,000,000 Mcf is free natural gas (non-associated); 2,000,000,000 Mcf is natural gas (associated) in immediate contact, but not in solution, with crude oil; and 3,000,000,000 Mcf is natural gas (dissolved) in solution with crude oil in the reservoir (Amer. Gas Assoc., 1961). The large reserves are in gas fields in the Panhandle and northwestern Oklahoma, but southeastern Oklahoma's Arkoma Basin is also emerging as a big new source of natural gas.

Natural gas production, which commenced in Oklahoma in 1902, amounted to more than 16,700,000,000 Mcf at the end of 1960. Of this cumulative production, nearly 7,000,000,000 Mcf has been marketed since 1950. The gas fields, shown on figure 83, have produced or are producing primarily non-associated natural gas, but the map does not show where associated gas has been or is being produced. In 1959, only 55% of the gas production came from the 5,300 wells classified as gas wells. As development proceeds and pipeline connections are made in northwestern Oklahoma, a greater percentage of natural gas will be produced from areas designated as gas fields. It is probable that gas will be exported primarily from this area.

In 1959, marketed production of natural gas in Oklahoma reached 811,508 MMcf, with an average value at the wellhead of 10.0 cents per thousand. Net export of gas transmitted by pipeline to industrial areas of eastern and north-central United States and to adjacent states amounted to 412,331,000 Mcf, or more than 50% of the total production. Consumption in Oklahoma amounted to 379,178,000 Mcf (Mineral Yearbook, vol. 2, Fuels, 1959, p. 303). There were 540,000 residential consumers, utilizing 59,763,000 Mcf at an average value of 66.8 cents per thousand. 58,000 commercial consumers used 27,602,000 Mcf valued at 43.3 cents per thousand. Other industrial users of natural gas, such as refineries, oil and gas field operators, and power plants, consumed 291,813,000 Mcf, valued at 15.3 cents per thousand. The value of natural gas at point of consumption in Oklahoma was estimated to be $96,413,000 in 1959 by the U. S. Bureau of Mines. The American Gas Association excluded revenues from sales for resale and arrived at a total revenue for utilities of $80,810,000.

Geological Conditions for Storage

Discussion of the complex structural geology and stratigraphy of the State of Oklahoma is beyond the scope of this report. References to subsurface mapping and stratigraphy for the period 1940-1960 may be found in the Oklahoma Geological Survey's 1961 publication, "Index to geologic mapping in Oklahoma." Figure 84 shows distribution of outcrop areas of rocks of various geologic systems and two generalized sections across the state, A-A' from the southwest corner to near the northeast corner and B-B' along the northern boundary of the state from Cimarron County in the Panhandle to Ottawa County at the east. Sedimentary rocks above the basement range in age from Upper Cambrian to a thin veneer of Mesozoic rocks in southern Oklahoma and in the Panhandle. The youngest rocks are of Pliocene age in the Panhandle region. Thickness of sedimentary rocks in basin areas probably reaches a maximum of 35,000 feet in the Anadarko Basin (cross section A-A'). Porous sandstone and limestone reservoirs for underground storage are present at most places. Areas in which such storage is least feasible are the Arbuckle Mountain, Ouachita Mountain, and Wichita Mountain provinces, and the Ozark region. The Early Paleozoic rocks of the Arbuckle Mountains are closely folded and faulted. Igneous rocks are at the surface in the Wichita Mountains. Mississippian sandstone and shale and older rocks are complexly faulted in the Ouachita Mountains. Mississippian and older carbonates, which are sources of ground water in the Ozark region, are probably of little interest as possible storage reservoirs because of lack of impermeable sealing beds.

Storage Facilities in Oklahoma

The primary reasons for operating underground gas storages are: (1) to balance relatively fixed-rate supplies of gas, such as gasoline-plant residue, with fluctuating gas sales and (2) to eliminate need

Figure 83. Map of Oklahoma showing location of active and abandoned gas fields. Areas of small new fields exaggerated in northwestern Oklahoma.

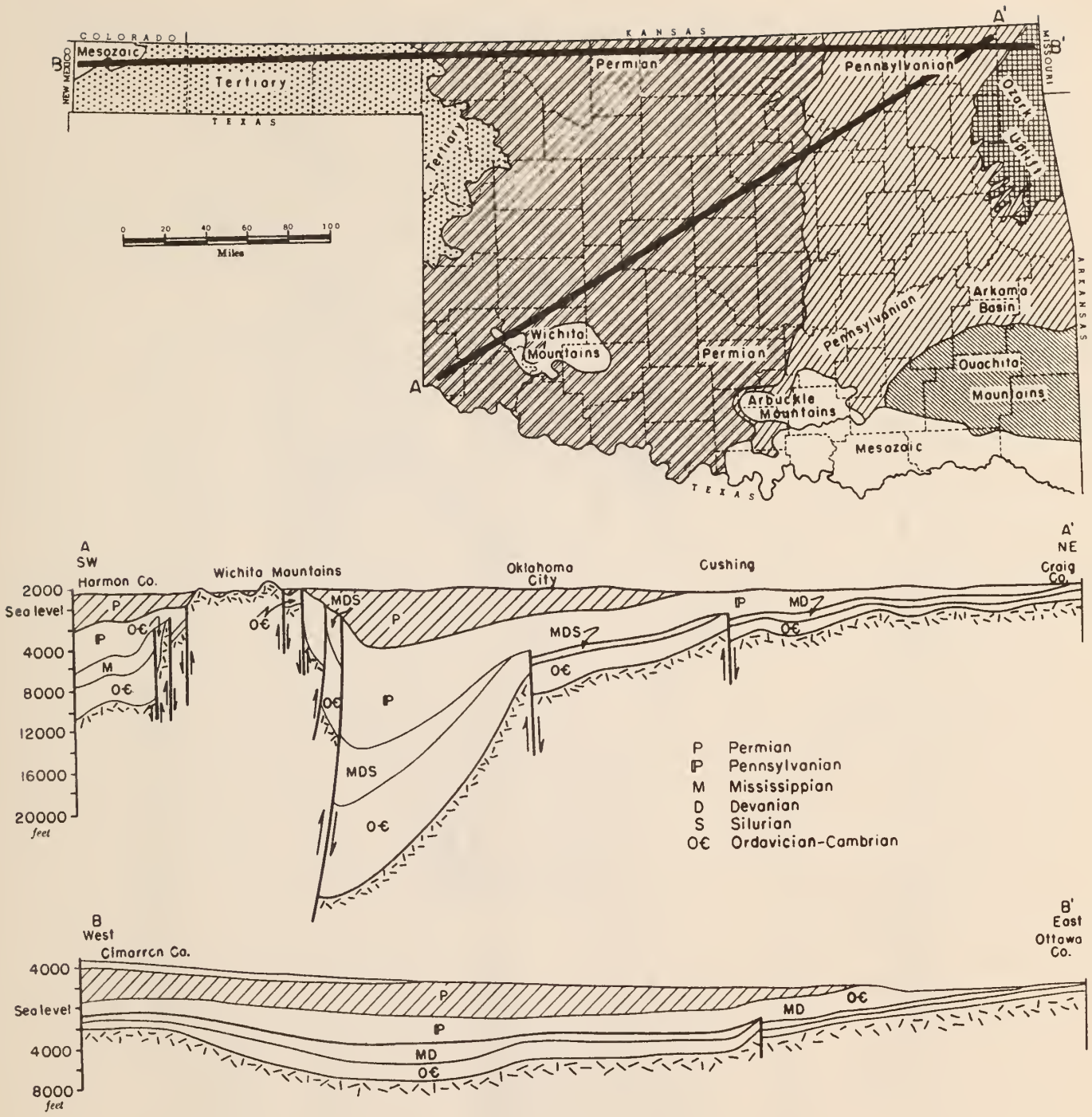


Figure 84. Generalized areal geologic map of Oklahoma and cross sections A-A' and B-B'

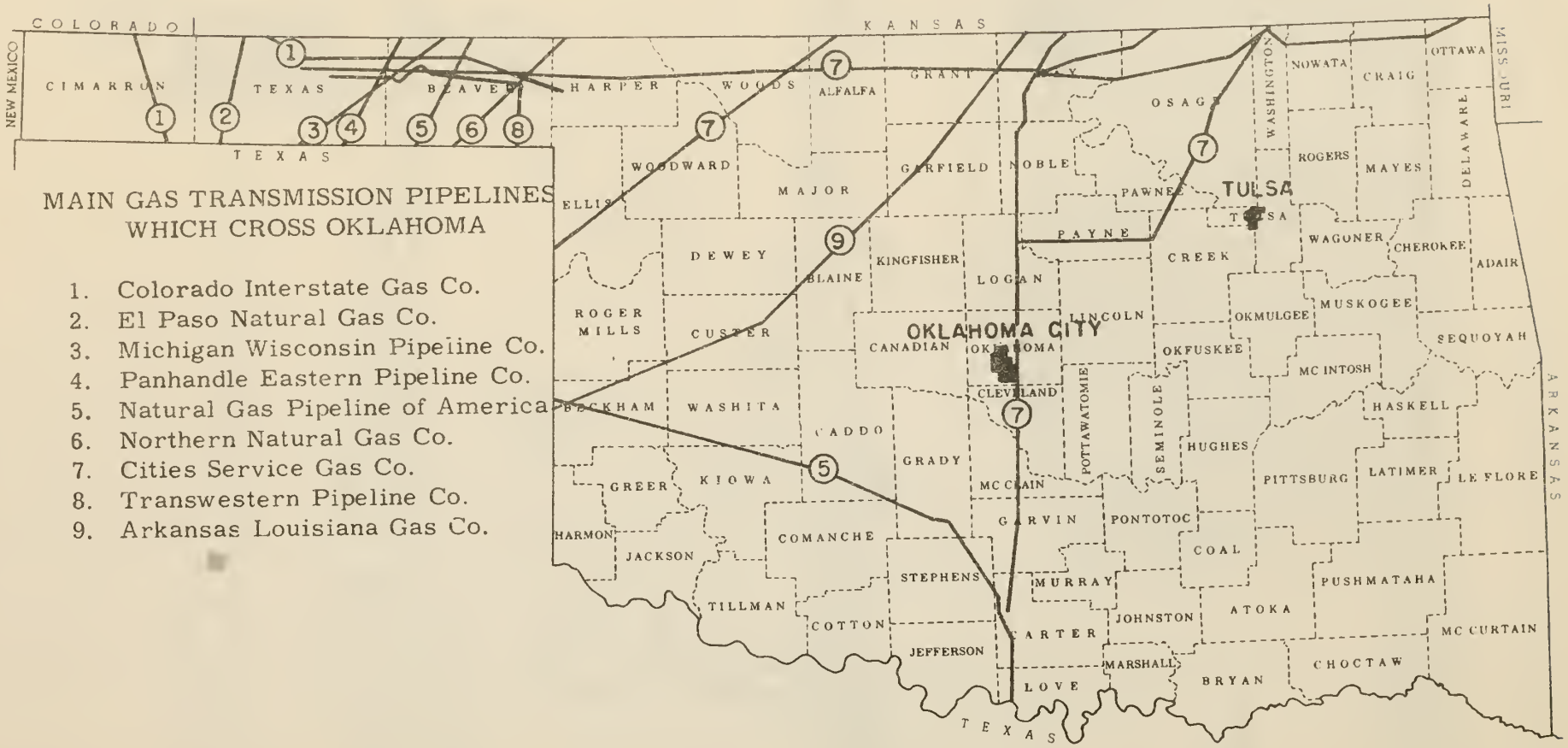


Figure 85. Major interstate gas transmission pipelines which cross Oklahoma

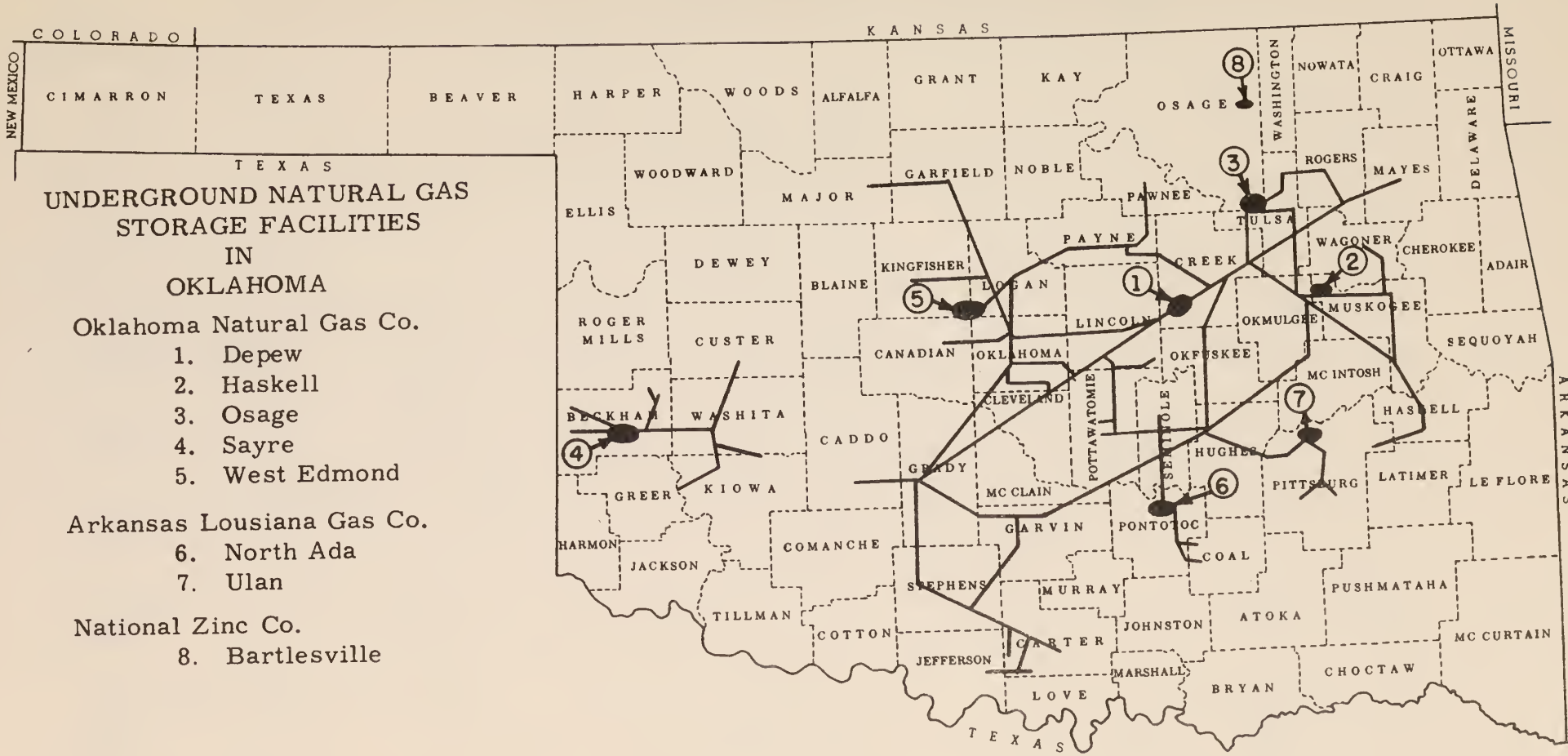


Figure 86. Map of Oklahoma showing location of underground natural gas storage facilities and principal related pipelines

Table 30. Underground Natural-Gas Storage Statistics in Oklahoma, 1961

Storage facility County Location	Year of discovery	No. of productive wells	Input-output wells	Observation wells	Storage surface area (acres)	Producing depth average (feet)	Date of first injection	Capacity, million cubic feet Cushion gas	Total reservoir	Structure Zone Age	Max. pressure (psig)
OKLAHOMA NATURAL GAS CO.											
1. Depew Creek secs. 25, 36, T. 15 N., R. 7 E., secs. 19, 20, 30, 31, T. 15 N., R. 8 E.	1922	32	11	0	7,360	3,250	5/6/50	37,400	63,500	Anticline Dutcher Pennsylvanian	1,480
2. Haskell Muskogee secs. 7-10, 14-20 T. 15 N., R. 15 E.	1914	51	17	3	7,000	800	6/12/44	8,400	12,500	Anticline, strat trap Booch Pennsylvanian	325
3. Osage Osage secs. 28, 29, T. 20 N., R. 12 E.	1922	32	7	0	1,920	1,600	4/21/43	1,900	3,200	Anticline Burgess Pennsylvanian	565
4. Sayre Beckham sec. 20, 21, 27, 28 T. 9 N., R. 23 W.	1922	32	6	1	5,000	2,650	10/12/53	23,410	89,300	Anticline Panhandle dolomite Permian	940
5. West Edmond Kingfisher and Logan sec. 27-30, T. 15 N., R. 4 W. sec. 25-27, T. 15 N., R. 5 W.	1944	38	16*		3,292	6,550	12/1961		59,000*	Monocline, strat trap Bartlesville Pennsylvanian	2,000
ARKANSAS LOUISIANA GAS CO.											
6. North Ada Pontotoc sec. 8-10, 16, 17, T. 4 N., R. 6 E.	1915	16	4	0	2,000	1,300	5/1944	5,564	6,557	Anticline, strat trap, faulted. Cromwell Pennsylvanian	425
7. Ulan Pittsburg sec. 31-33, T. 8 N., R. 14 E. sec. 4-6, T. 7 N., R. 14 E.	1945	12	4	8	3,250	1,000 2,000	1/1953	6,005	13,500	Anticline, faulted, Booch (2,000-foot depth) Pennsylvanian	470
NATIONAL ZINC CO.											
8. Bartlesville	(No report)										

*Estimated

Total reservoir capacity (million cubic feet) 247,557

for additional pipelines or peak-load shaving devices near major markets. The locations of underground storage reservoirs are controlled by the needs of pipeline companies rather than by the availability of suitable fields. In general, there are a great many abandoned gas fields or abandoned gas zones in the east-central and northeast portions of the state which could be converted to underground storage, whereas there are virtually none in the northwest part of the state, where, at present, most of the reserves are located, and where most of the major interstate gas transmission pipelines are situated (figure 85). Thus, even though there are many areas suitable for gas storage in abandoned fields in Oklahoma, this fact probably will have little bearing on the construction of large storage fields for major transmission pipelines in the near future.

Underground storage of natural gas in Oklahoma is related directly to the major non-industrial (fluctuating) markets of the state. Figure 86 is a map of Oklahoma showing location of the eight underground storage facilities now in operation and of the network of pipelines related to these facilities. Storage reservoirs at Depew, Haskell, Osage, and West Edmond, owned by Oklahoma Natural Gas Company, are for peak-load requirements of Oklahoma City and Tulsa. Oklahoma Natural's Sayre storage serves the Sayre-Clinton area. The North Ada storage, developed by Southwest Natural Gas Company, supplies gas to Ada, and during winter peak-periods supplies some gas to Seminole. The Ulan facility in Pittsburg County, installed by Consolidated Gas Utilities Corporation, serves McAlester, Krebs, and Savanna The last two facilities are now owned by the Arkansas Louisiana Gas Company. An eighth storage is operated by by the National Zinc Company to facilitate the fuel requirements of their smelter near Bartlesville. Pertinent data for each of the storage facilities are listed in table 30.

Possibilities for Additional Storage

In almost all parts of Oklahoma, geologic conditions are favorable for storage of natural gas in porous rocks. Additional storage fields may be economically feasible in the future near some of the smaller cities of the state. Through economic necessity, such fields would be located near the cities which they would serve. In the future some of the interstate pipeline companies, which have pipelines primarily in the western part of the state, may require underground storage reservoirs in order to balance their steady gas supplies with their fluctuating summer-winter markets. Ideally such storage fields would be located near markets, but if no fields were available in market areas it might be feasible to have underground storage in supply areas. These companies rely mainly on interruptible industrial loads to balance their supplies and sales. In other words, during peaks of residential and commercial consumption, companies decrease the amount deliverable to industrial users. However, increased well-head gas prices in the future might cause supply-area underground storage facilities to be more economical than interruptible gas sales to industrial customers at relatively low rates. Should such a condition come about, the pipeline companies will develop suitable reservoirs in porous limestone or sandstone, or possibly in cavities artificially dissolved in Permian salt layers. Each type of formation can be found readily in northwestern Oklahoma and the Panhandle.

OREGON

Vernon C. Newton, Jr., Petroleum Engineer
State of Oregon Department of Geology and Mineral Industries
David Don, Chief Engineer
State of Oregon Public Utility Commissioner

Summary

Underground storage for petroleum gas will not be an important matter in Oregon for at least a few years, and as yet no regulations or provisions in state law cover underground storage. Reservoir sites probably can be found in some of the anticlinal folds of the marine Tertiary basin in western Oregon, but much more subsurface geologic information is needed before specific locations can be named.

General Remarks

A canvass of the three distributors of natural gas in Oregon indicates that no consideration is being given by any of them at this time for underground storage of natural gas. There are many reasons given for this, but primarily it is because of the many sources from which natural gas is, or will be, brought into the area and the present rate-structure of their supplier, El Paso Natural Gas Company. Northwest Natural Gas Company also maintains its oil-gas manufacturing plant in standby operating condition for

emergency use in its Portland and Willamette Valley service area.

Gas Pipelines in Oregon

Up to the present no oil or gas have been produced in commercial quantities within the state, so all gas used is imported.

Figure 87 is a map of the El Paso Natural Gas Company systems. Dotted lines have been added to show proposed pipelines through central Oregon and the central Willamette Valley of western Oregon. The latter system indicates new city gates east of Portland, Milwaukee, Salem, Albany, and Eugene.

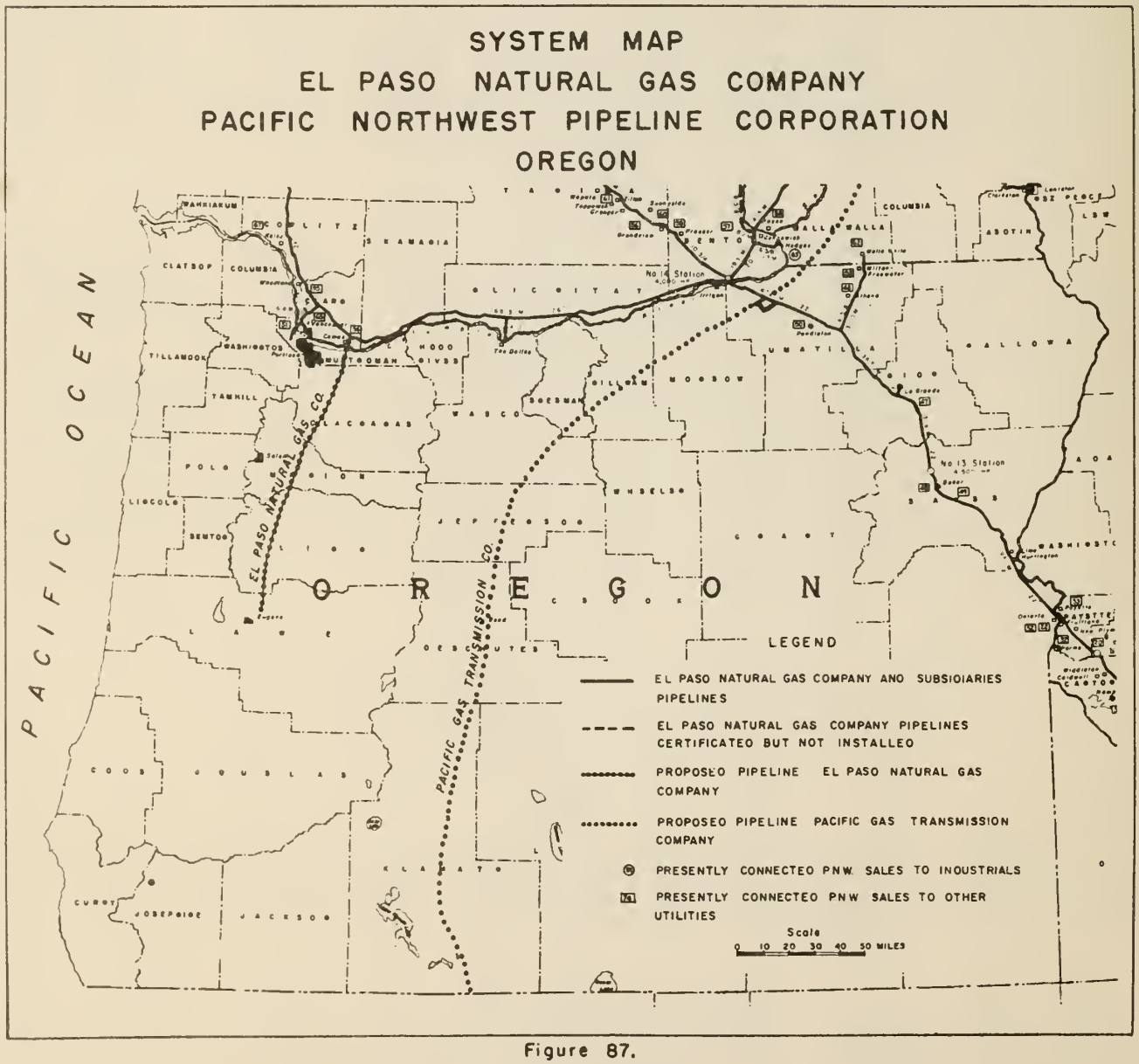


Figure 87.

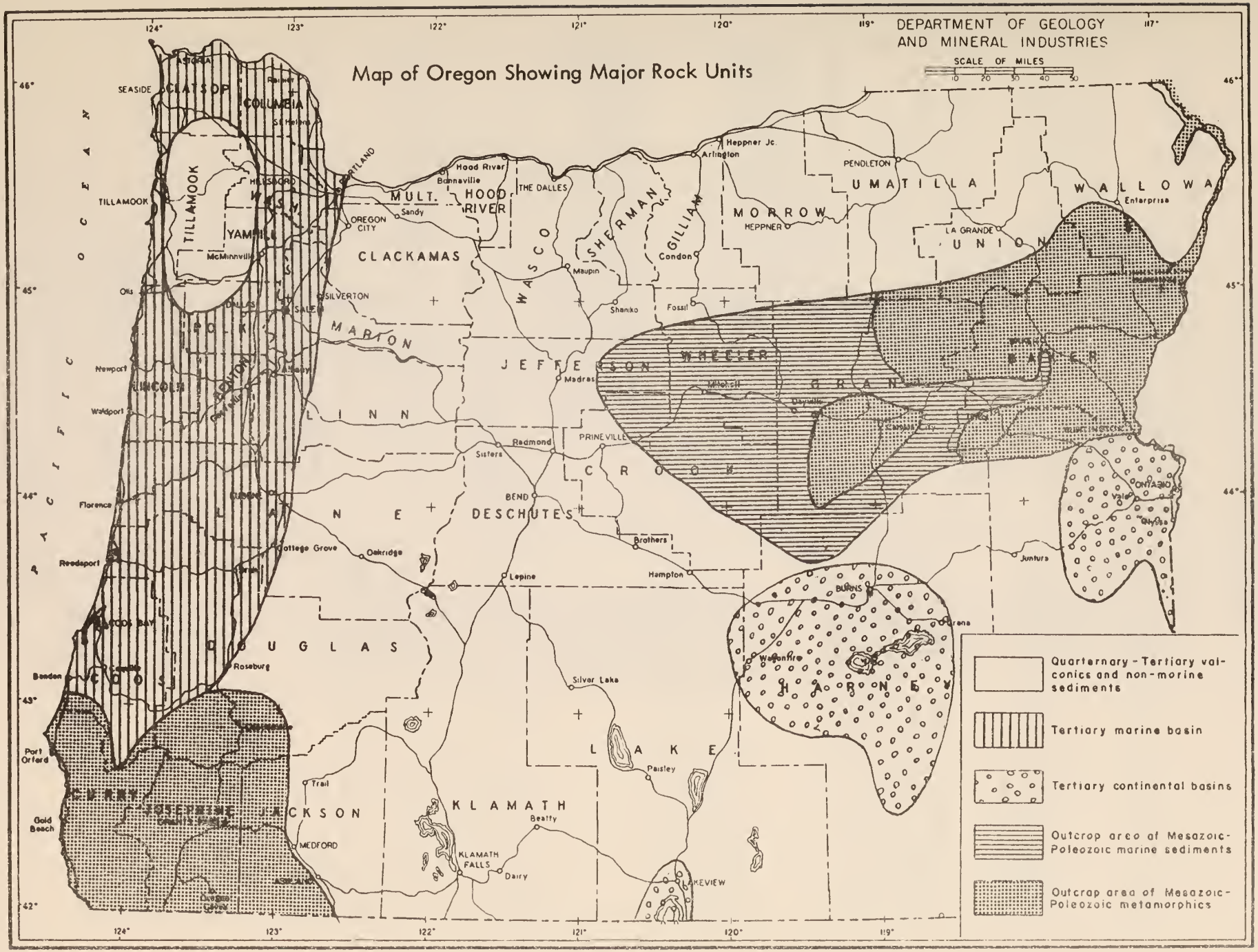

Map of Oregon Showing Major Rock Units
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
SCALE OF MILES
10 20 30 40 50
PACIFIC OCEAN
CLATSOP
COLUMBIA
TILLAMOOK
YAMHILL
WASH.
POLK
LINCOLN
BENTON
MARION
LINN
LANE
DOUGLAS
COOS
CURRY
JOSEPHINE
JACKSON
KLAMATH
LAKE
DESCHUTES
CROOK
JEFFERSON
WASCO
SHERMAN
GILLIAM
MORROW
UMATILLA
UNION
WALLOWA
WHEELER
GRANT
BAKER
HARNEY
MULT.
HOOD RIVER
CLACKAMAS
SEASIDE
TILLAMOOK
Oils
Newport
Waldport
Florence
Reedsport
Bandon
Port Orford
Gold Beach
Roseburg
Cottage Grove
Oakridge
Lapine
Sisters
Redmond
BEND
Brothers
Hampton
Silver Lake
Paisley
Beatty
KLAMATH FALLS
Dairy
LAKEVIEW
Trail
MEDFORD
Madras
Maupin
Shaniko
Fossil
Condon
Arlington
Heppner Jc.
HEPPNER
PENDLETON
LA GRANDE
Enterprise
Juntura
Vale
Nyssa
ONTARIO
BURNS
Grana
Wagontire
Mitchell
Dayville
Sandy
Bonneville
Hood River
THE DALLES
OREGON CITY
SILVERTON
SALEM
DALLAS
McMinnville
HILLSBORO
PORTLAND
Albany
Cuba
Coquille
Rainier
St. Helens
ASTORIA
Oregon Caves
Quarternary - Tertiary volcanics and non-marine sediments
Tertiary marine basin
Tertiary continental basins
Outcrop area of Mesozoic-Paleozoic marine sediments
Outcrop area of Mesozoic-Paleozoic metamorphics

Figure 88.

GENERALIZED CORRELATION TABLE
NORTHWEST OREGON

Stream deposits in major valleys

Older terrace deposits. Loess and silts of Portland hills. Boring lava from local vents in Portland area.

Boring agglomerate pyroclastics in Portland and Clackamas river area. Pliocene lavas extensive in western cascades - locally tuffs. Troutdale gravels deposited by the Columbia River, equivalent to Satsop formation.

Columbia River basalt - Thick series of flows in Columbia River gorge (3,000 ft.) Salem area 500 ft ±. To south exposures scattered and correlation is questionable.

Eugene formation - Marine tuffs of Willamette Valley Interfingers with Terrestrial Mehama in Cascade foothills. Fisher in Cottage Grove area. Keasey and Cowlitz in northern Coast Range. Tyee and Umpqua in Coast Range. Tyee extends to western Cascades in Umpqua River area. Tillamook - Northern Coast Range and Siletz River volcanics to south form core of Coast Range- - 10,000 ft. thick ±

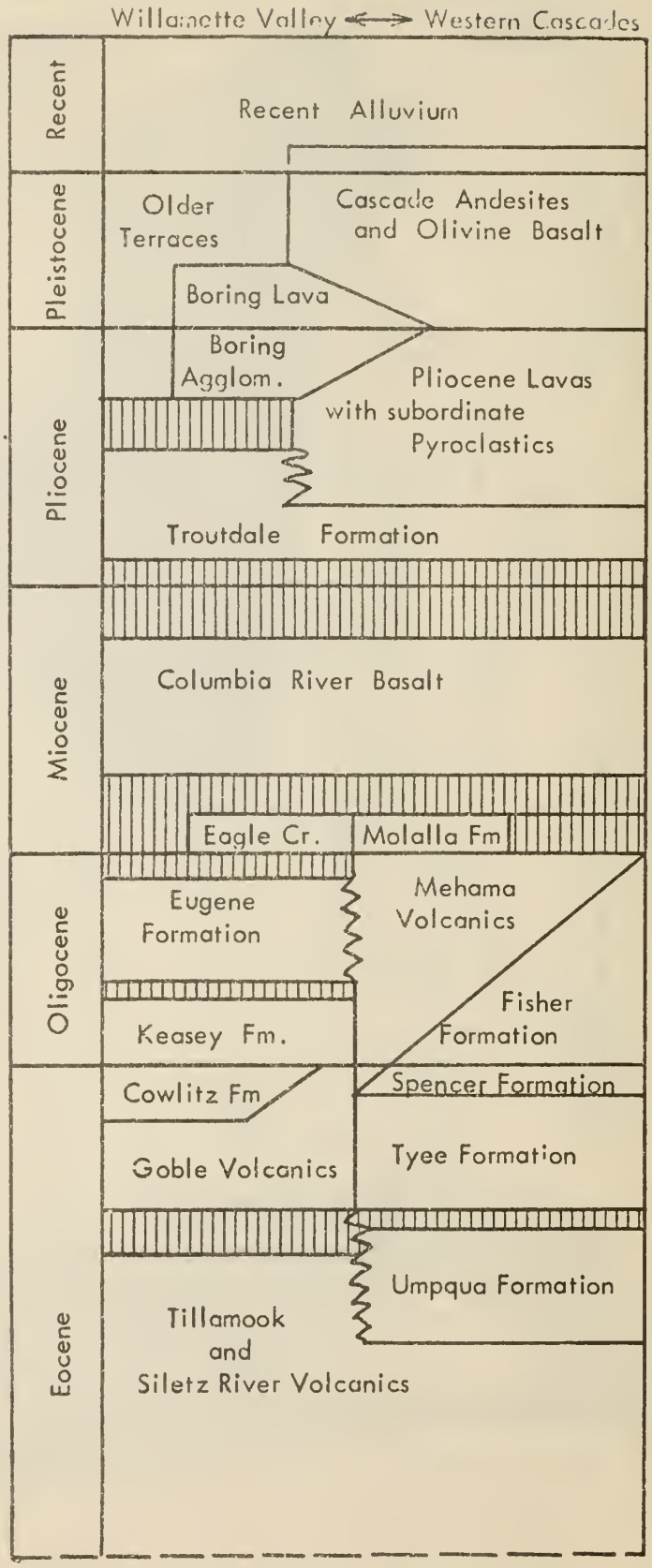
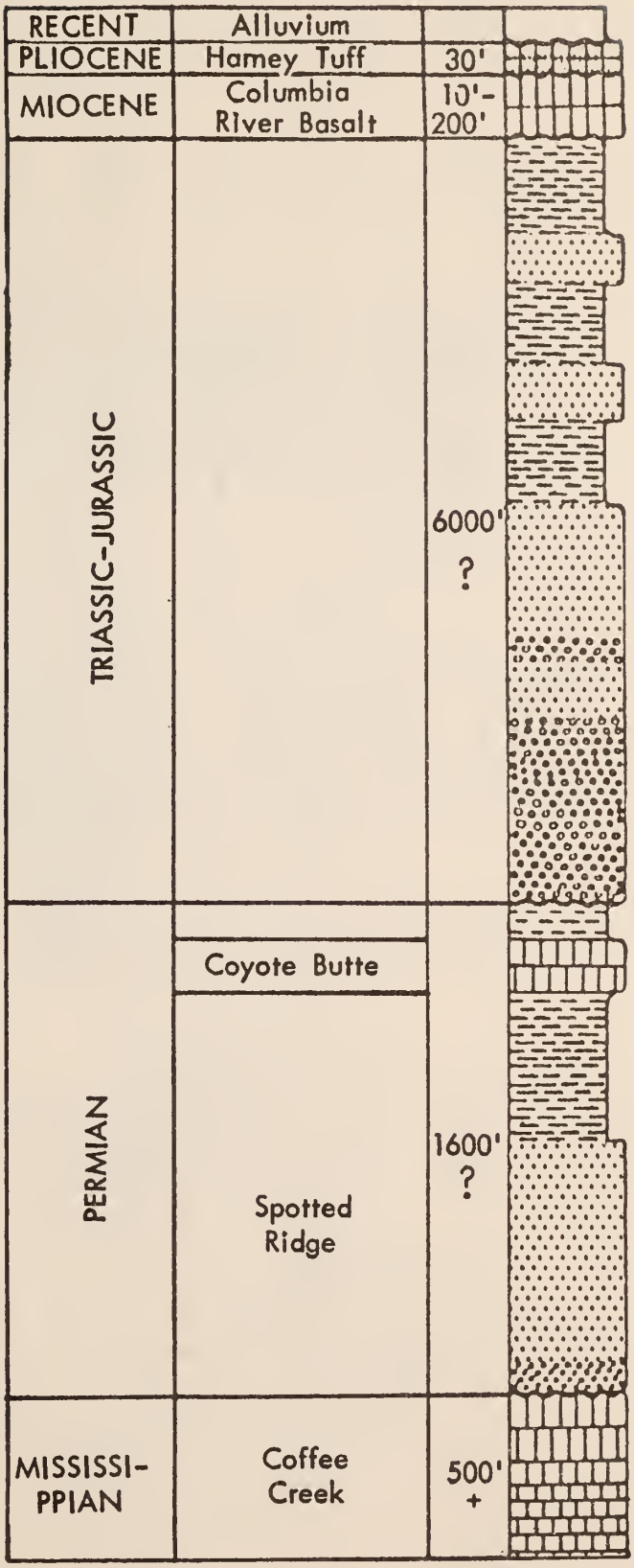


Figure 89

CENTRAL OREGON

COLUMNAR SECTION



D. E. Ogren, 1958

Figure 90.

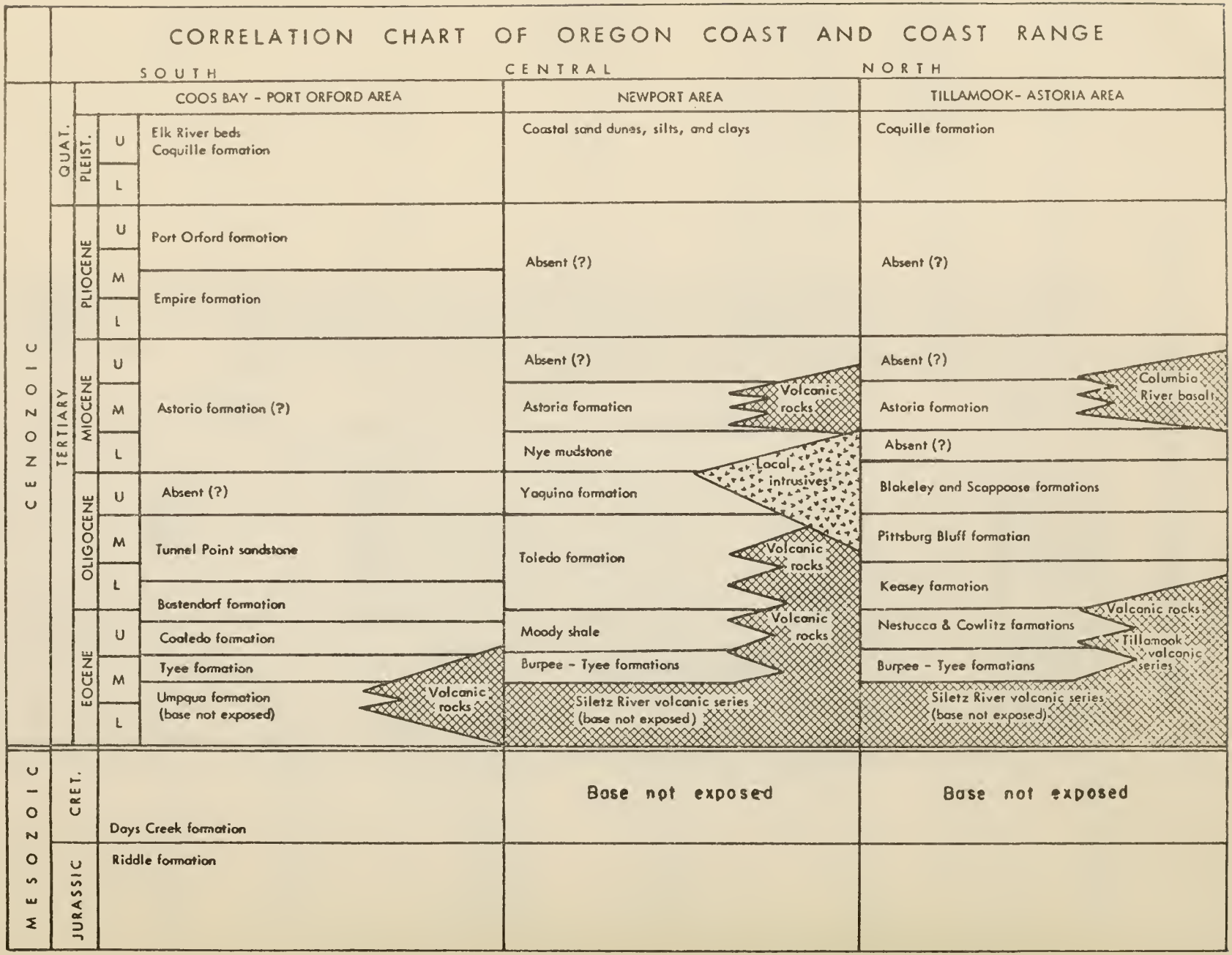

CORRELATION CHART OF OREGON COAST AND COAST RANGE
SOUTH
CENTRAL
NORTH
COOS BAY - PORT ORFORD AREA
NEWPORT AREA
TILLAMOOK- ASTORIA AREA
CENOZOIC
QUAT.
PLEIST.
U
L
Elk River beds
Coquille formation
Coastal sand dunes, silts, and clays
Coquille formation
TERTIARY
PLIOCENE
U
M
L
Port Orford formation
Empire formation
Absent (?)
Absent (?)
MIOCENE
U
M
L
Astoria formation (?)
Absent (?)
Astoria formation
Nye mudstone
Volcanic rocks
Absent (?)
Astoria formation
Absent (?)
Columbia River basalt
OLIGOCENE
U
M
L
Absent (?)
Tunnel Point sandstone
Bastendorf formation
Yaquina formation
Toledo formation
Local intrusives
Volcanic rocks
Blakeley and Scappoose formations
Pittsburg Bluff formation
Keasey formation
EOCENE
U
M
L
Coaledo formation
Tyee formation
Umpqua formation (base not exposed)
Volcanic rocks
Moody shale
Burpee - Tyee formations
Siletz River volcanic series (base not exposed)
Volcanic rocks
Nestucca & Cowlitz formations
Burpee - Tyee formations
Volcanic rocks
Tillamook volcanic series
Siletz River volcanic series (base not exposed)
MESOZOIC
CRET.
Days Creek formation
Base not exposed
Base not exposed
JURASSIC
Riddle formation

Figure 91.

Geology of Oregon with Reference to Gas Storage

The bulk of the rocks exposed at the surface in Oregon are Tertiary or younger in age with volcanics constituting the largest portion. The accompanying geologic map (figure 88) shows major rock groups. Typical stratigraphic sections are shown in figures 89, 90, and 91.

Tertiary marine sediments lie in a broad strip along the western side of the state from the north border to a short distance south of Coos Bay. The dimensions of the strip are roughly 80 miles by 220 miles. Rocks of this area form a broad arch in which many minor folds occur. These rocks range in age from Lower Eocene to Upper Miocene. Pliocene deposits are represented by marine terraces and filled estuaries along the coast.

To the south of the Tertiary marine basin lie the older rocks of the Klamath Mountains composed of Mesozoic marine sediments and volcanics intruded in places by ultrabasic and granitoid rocks. These rocks have been tightly folded, considerably faulted, and moderately to extremely metamorphosed

East of the Cascade Range in Oregon the rocks are predominantly Cenozoic volcanics and associated terrestrial sediments within which several large intermountain sedimentary basins have been formed. The rocks have been folded into large broad structures at places throughout the region.

In the east-central portion of the state lies a region of Mesozoic and Upper Paleozoic outcrops. Part of this region consists of marine sandstone, conglomerate, limestone, chert, and shale which, for the most part, are unmetamorphosed. Here several large northeast-southwest trending folds might provide storage space if porous beds were found in them. Since central Oregon has no large cities, gas storage will not be a problem there until population increases.

Because the Willamette Valley of western Oregon is the most thickly populated part of the state, gas storage may some day become a problem in this region. Only 12 deep wells providing good subsurface geologic information have been drilled in western Oregon. As a result, relatively little is known about underground conditions. From information that is available, however, it appears that the most likely gas storage prospects in western Oregon are in Columbia, Multnomah, and Washington Counties. Porous sands were encountered in drillings made by the Texas Company and the Richfield Oil Corporation between depths of 1,500 and 3,500 feet in the three northwestern counties. No tests were run on these sands, but some core data is available.

Underground mine workings, particularly at the Benton and California mines in the Mt. Reuben Mining District of southwestern Oregon, might be of interest for gas storage. The Benton Mine has more than 10,000 feet of crosscuts, drifts, and raises. The tunnels are made in quartz diorite and ultrabasic igneous rocks. This mining district is situated in northern Josephine County between Roseburg and Grants Pass.

Regulations Affecting Underground Storage

There are no provisions in the present oil and gas law regulating underground storage of petroleum gas. The Public Utility Commissioner regulates surface storage and transmission of gas within the state but has as yet no rules covering underground storage.

PENNSYLVANIA

William S. Lytle
Assistant State Geologist

Abstract

At the close of 1960 Pennsylvania had 61 active natural gas storage pools. The gas is stored in depleted gas pools in rocks from Silurian to Pennsylvanian age from 1,000 feet to 6,000 feet in depth. The storage pools occupy stratigraphic rather than structural traps in Pennsylvanian, Mississippian, Upper Devonian, and Lower Silurian (Medina) strata. In contrast, the gas stored in the Oriskany Sandstone (Lower Devonian in age) pools occupies structural traps consisting of elongated domes along the prominent anticlines. Pennsylvania is the ranking state in all phases of gas storage. The following figures for 1960

are published by the AGA for Pennsylvania: the maximum gas storage, 485,000,000 Mcf; total input, 227,000,000 Mcf; maximum daily output, 2,859,000 Mcf; total output, 177,000,000 Mcf; and ultimate capacity, 497,000,000 Mcf.

Introduction

Following the drilling of the world's first commercial oil well, the Drake Well at Titusville, Pennsylvania, in 1859, rapid discovery and development of Pennsylvania's oil and gas fields took place. Most of the state's shallow oil and gas fields were discovered and developed before the turn of the century. Gas was piped 5 1/2 miles to Titusville, Pennsylvania, in 1872 and about 11 miles from Murrysville to Pittsburgh in 1883.

To store natural gas in the early days, the natural gas industries used gas holders, pipelines, auxiliary artificial gas plants, and gas wells which were used only during periods of peak seasonal or daily demand. In 1915 gas was first successfully stored underground in Welland County, Ontario, Canada. The second underground storage of natural gas was effected in the Zoar Field in Buffalo, New York, in 1916.

During the First World War serious natural gas shortages developed, and curtailments were necessary. After the war the demands for natural gas decreased, and the supply situation improved, but even in these years meeting the peak during periods of cold weather was a major problem of the gas companies. To the operators of the gas systems it became apparent that storage pools were needed that would deliver large volumes of gas for a few days at a time. Relatively small storage pools were developed to meet the situation.

The Central Kentucky Natural Gas Company of Lexington was one of the first companies to utilize underground storage by developing such storage in the Menifee Field, Kentucky, in 1919. Pennsylvania's first storage project was developed the following year by the United Natural Gas Company when it converted the Queen gas pool in Warren and Forest Counties to a gas storage pool.

Little was done about underground storage of natural gas in Pennsylvania, or in the rest of the Appalachian area, until 1934 when several storage pools were put into operation. The rapid growth in popularity of underground gas storage during the past 27 years has centered around the depleted oil and gas fields in or near the large market areas. Today there are 61 natural gas storage pools in Pennsylvania. Additional pools are under development. The names and locations of the natural gas storage projects and the locations of the oil and gas fields are shown on figure 92.

Gas Production in Pennsylvania

Pennsylvania's first gas field was discovered in Erie County in 1860 at shallow depths along Lake Erie. It is definitely known that natural gas was used commercially in 1872 in Titusville, Pennsylvania; it was probably produced and sold in Pennsylvania previous to 1872. No statistics were kept on the quantity and value of natural gas produced until 1882. From 1882 to 1906 only the value of gas produced was recorded. From these values it was computed that the peak year of natural gas production in the state was 1888 when approximately 241,000,000 Mcf of gas were produced. A secondary peak occurred in 1906 when the production amounted to 138,161,385 Mcf. From 1906 to 1932 the production gradually declined to about 61,000,000 Mcf. The discovery of Oriskany gas in the state increased the production to about 115,000,000 Mcf in 1937 and to over 158,000,000 Mcf in 1954. The cumulative total production of natural gas in the state by the end of 1959 was 7,290,749,000 Mcf. The reserve figure for the same date as published by the AGA is 1,051,972,000 Mcf. During the 79 years from 1882 to 1960 inclusive, the annual natural gas production has been below 100,000,000 Mcf 20 times, but has never fallen below 60,000,000 Mcf.

Oriskany sand production (Lower Devonian) was discovered in September 1930 in Tioga County. Discoveries in the deeper horizon have continued. Today a number of these discoveries are gas storage pools. By the end of 1959 the Leidy Field had produced a cumulative total of 153,500,000 Mcf of gas from the Oriskany sand. As of the same date the Benezette-Driftwood Pool had produced 217,000,000 Mcf of gas from the Oriskany. Exploratory work is continuing in the deeper horizons in an effort to find additional oil and gas.

Since 1921 Pennsylvania has consumed more gas than it has produced. Until 1943 the supply was augmented by gas from other states in the Appalachian area. The first deliveries of gas from the western

GAS STORAGE FIELDS OF PENNSYLVANIA

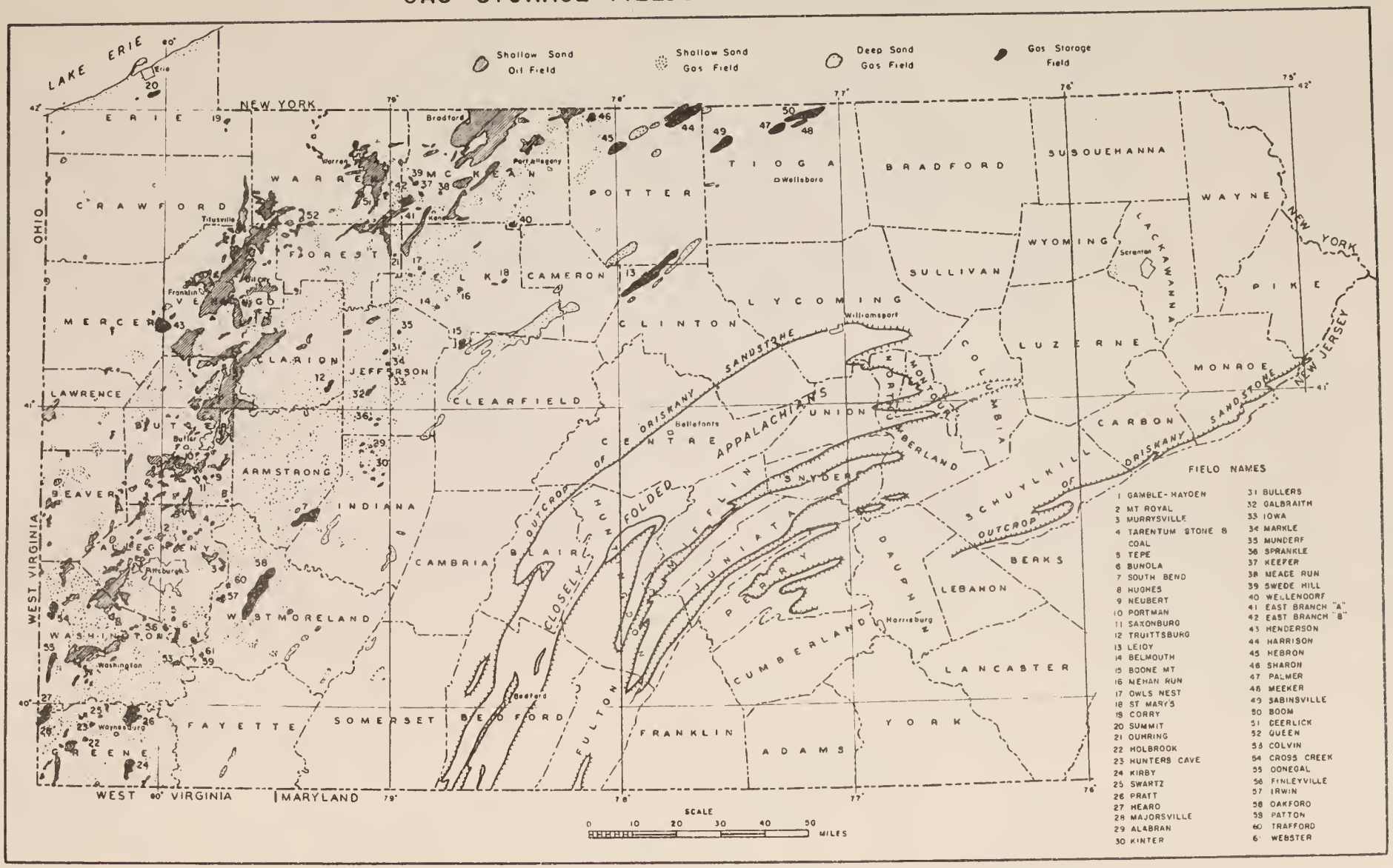


Figure 92

part of the United States took place in 1943. Today over two billion cubic feet of gas are purchased daily by the gas companies from sources outside the state. The chief suppliers are Tennessee Gas Transmission, Texas Eastern Gas Transmission, and Transcontinental Pipeline. Figure 93 shows the location of the principal natural gas pipe lines in the state. Most of the gas brought into the state has been transported some 1,400 miles from Mexico, Texas, Gulf of Mexico, and Louisiana. About 85% of the natural gas used in Pennsylvania today comes from sources outside the state.

Structures and Stratigraphy as Related to Gas Storage

The state may be divided into five physiographic areas (figure 94): (1) the Appalachian Plateaus Province in which the rocks dip gently to the south; (2) the Allegheny Mountain Section in which the rocks are gently folded, the folding dying out toward the west and north in the eastern part of the Appalachian Plateaus Province; (3) the Ridge and Valley Section in which the rocks are highly folded; (4) the Appalachian Valley Section, underlain mainly by shale, limestone and sandstone, which are intensely folded, crushed, broken, and somewhat metamorphosed; (5) the southeastern districts, where the rocks are igneous or are ancient altered rocks.

The rocks exposed at the surface in Pennsylvania range from Quaternary to Precambrian in age (figure 95). At the present time all of the natural gas storage is in sedimentary rocks. All of the storage pools are in the Appalachian Plateaus Province except two which lie along the western edge of the Allegheny Mountains Section.

Stratigraphy

The succession and nature of the formations underlying the Appalachian Basin in Pennsylvania are shown in table 31 along with data pertinent to natural gas storage. The stratigraphic positions of the more important oil and gas bearing sands as developed in Pennsylvania are shown in figure 96 for the part of the column which contains the Upper Devonian and in figure 97 for the older producing horizons.

In central Pennsylvania, in the closely folded Appalachian Mountains, the exposed Upper Cambrian to Mississippian section inclusive has a thickness of over 30,000 feet. The corresponding interval in central Ohio includes less than 5,000 feet of strata due to the thinning of many of the formations westward and the cutting out of others by unconformities.

The reservoir rocks in which oil and gas in commercial quantities have been found in Pennsylvania range in age from Pennsylvanian to Silurian.

In southwestern Pennsylvania the sandstones in the Pennsylvanian System have yielded substantial volumes of gas and oil. Gas is being stored in these sandstones in storage pools located in Greene and Washington Counties. In the central part of western Pennsylvania these same sandstones yield fresh or brackish water, while in the northwestern part of the state they have been eroded or never deposited.

The Mississippian Sandstones have been important sources of both gas and oil in western Pennsylvania. The Big Injun and Berea have produced considerable oil. The Murrysville Sandstone at the base of the Mississippian has been a great producer of gas and is now being used as a storage reservoir in the southwestern part of the state.

The major part of the oil production in Pennsylvania and large volumes of gas have come from the Upper Devonian Sandstones. The Conewango, Conneaut, and Canadaway Formations are contained in this section. The most important is the Conewango which contains a large number of gas storage reservoirs. Part of the Oakford Storage Field in Westmoreland County, which is one of the largest in the state, uses the Fifth sand as a storage reservoir. The lower part of the Upper Devonian is composed of unimportant shales and sandy shales. Suitable storage reservoirs of Upper Devonian age have yet to be found in northeastern Pennsylvania.

In the Middle Devonian, the Onondaga limestone and chert extend at depth over western and northeastern Pennsylvania. The Onondaga is gas productive in fracture-type porosity in the southern half of the western part of the state. Storage possibilities in this horizon should be of interest in the future.

The Oriskany sand of Lower Devonian age is the state's most important storage horizon. It is productive of gas in numerous areas. Although deeply buried, there are nine active Oriskany storage pools in

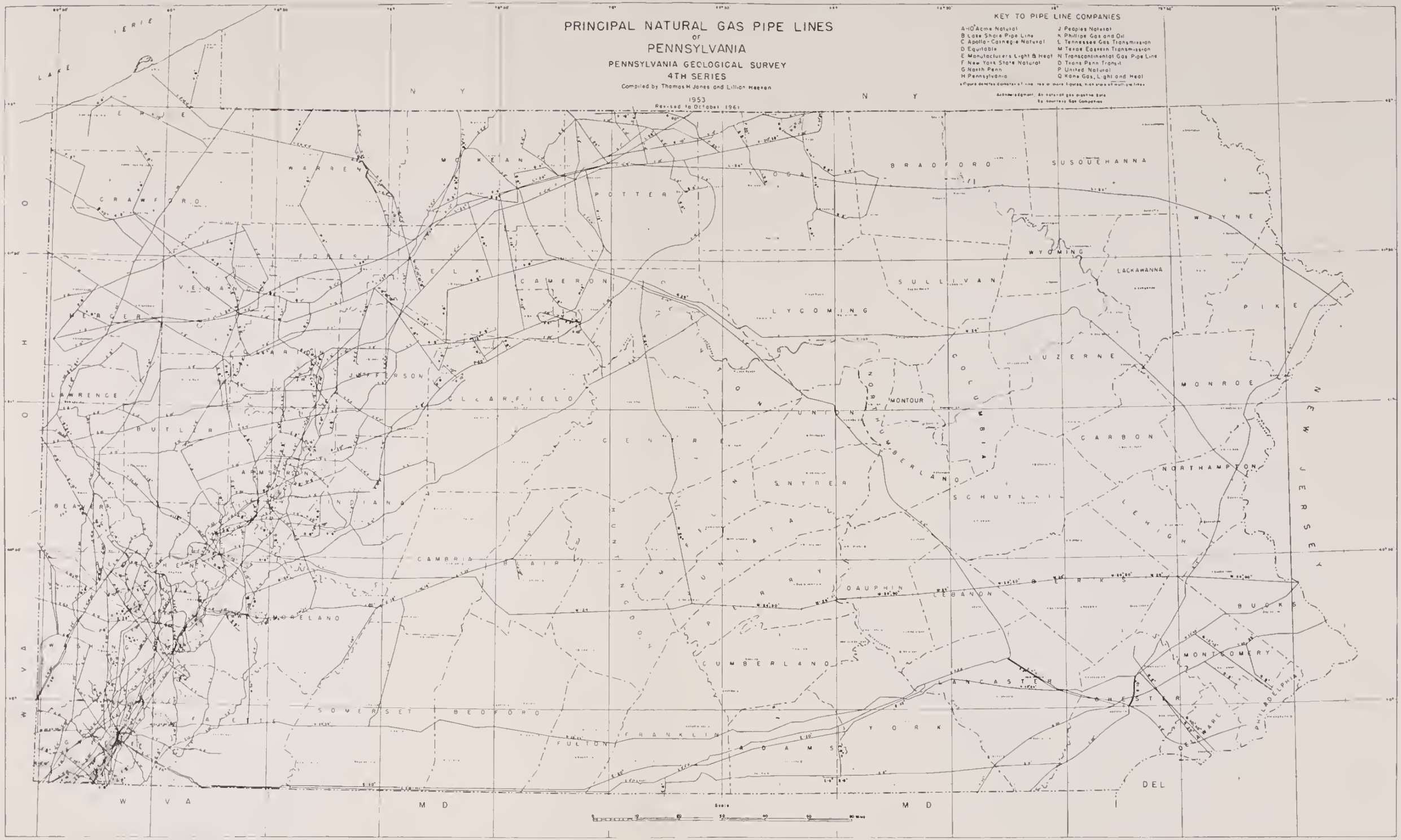

PRINCIPAL NATURAL GAS PIPE LINES
OF
PENNSYLVANIA
PENNSYLVANIA GEOLOGICAL SURVEY
4TH SERIES
Compiled by Thomas H Jones and Lillian Heeren
1953
Revised to October 1961
KEY TO PIPE LINE COMPANIES
A-10" Acme Natural
B Lake Shore Pipe Line
C Apollo-Carnegie Natural
D Equitable
E Manufacturers Light & Heat
F New York State Natural
G North Penn
H Pennsylvania
J Peoples Natural
K Phillips Gas and Oil
L Tennessee Gas Transmission
M Texas Eastern Transmission
N Transcontinental Gas Pipe Line
O Trans Penn Transit
P United Natural
Q Kane Gas, Light and Heat
LAKE ERIE
N Y
O H I O
W V A
M D
DEL
NEW JERSEY
ERIE
CRAWFORD
WARREN
MCKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
FOREST
ELK
CAMERON
VENANGO
MERCER
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
PIKE
LUZERNE
MONROE
LAWRENCE
BUTLER
JEFFERSON
CLEARFIELD
CENTRE
UNION
MONTOUR
COLUMBIA
CARBON
NORTHAMPTON
ARMSTRONG
INDIANA
SNYDER
SCHUYLKILL
LEHIGH
BEAVER
CAMBRIA
BLAIR
HUNTINGDON
MIFFLIN
JUNIATA
PERRY
DAUPHIN
LEBANON
BERKS
BUCKS
WASHINGTON
MORELAND
CUMBERLAND
MONTGOMERY
LANCASTER
CHESTER
PHILADELPHIA
FAYETTE
SOMERSET
BEDFORD
FULTON
FRANKLIN
ADAMS
YORK
DELAWARE
Scale

Figure 93.

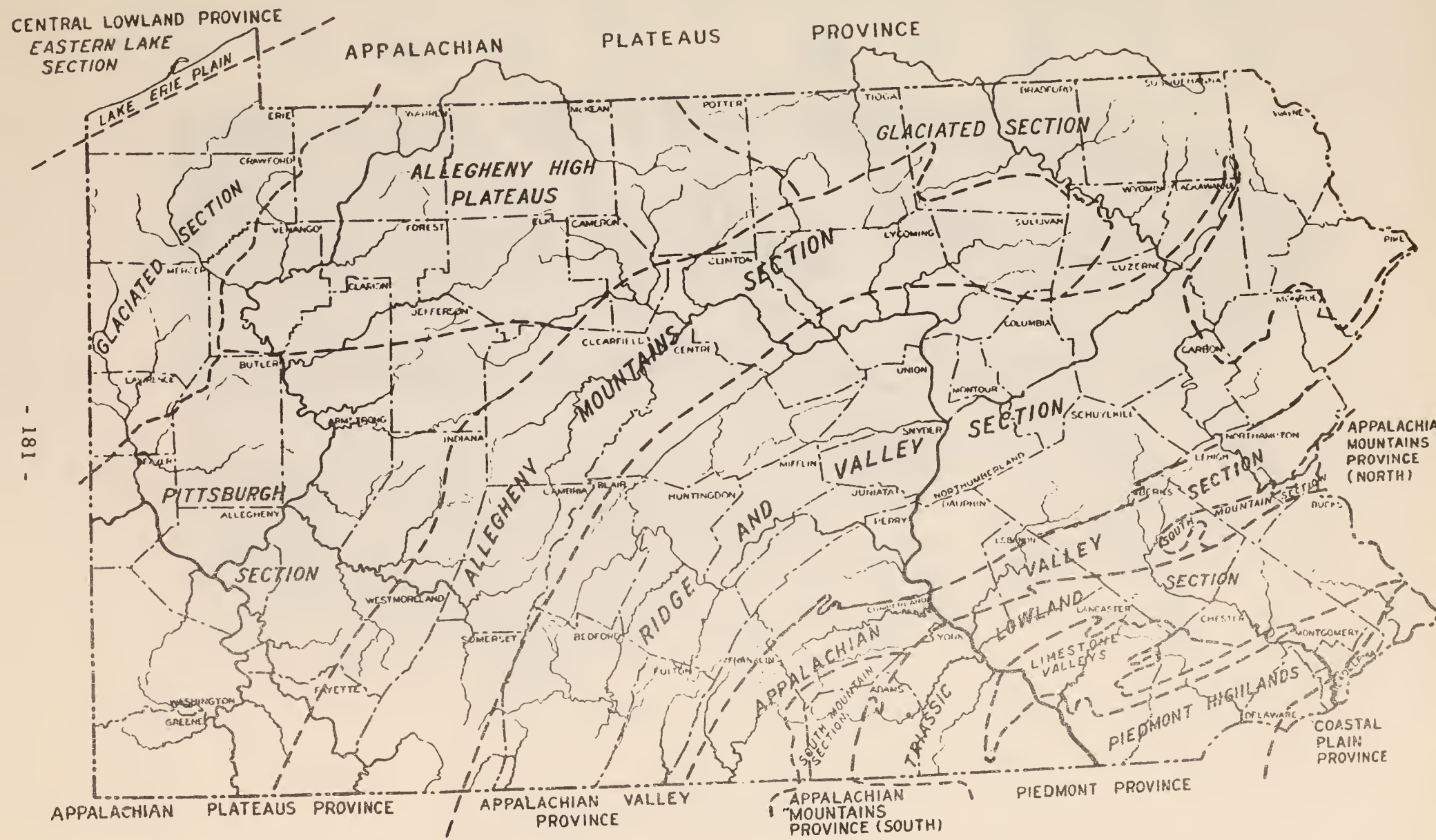

CENTRAL LOWLAND PROVINCE
EASTERN LAKE SECTION
LAKE ERIE PLAIN
APPALACHIAN PLATEAUS PROVINCE
GLACIATED SECTION
ALLEGHENY HIGH PLATEAUS
GLACIATED SECTION
PITTSBURGH SECTION
ALLEGHENY MOUNTAINS SECTION
ALLEGHENY RIDGE AND VALLEY
APPALACHIAN VALLEY
SOUTH MOUNTAIN SECTION
LIMESTONE VALLEYS
TRIASSIC LOWLAND
PIEDMONT HIGHLANDS
COASTAL PLAIN PROVINCE
APPALACHIAN MOUNTAINS PROVINCE (NORTH)
APPALACHIAN PLATEAUS PROVINCE
APPALACHIAN VALLEY PROVINCE
APPALACHIAN MOUNTAINS PROVINCE (SOUTH)
PIEDMONT PROVINCE
ERIE
WARREN
MCKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
VENANGO
FOREST
ELK
CAMERON
WYOMING
LACKAWANNA
SULLIVAN
LYCOMING
PIKE
MERCER
CLARION
JEFFERSON
CLINTON
LUZERNE
MONROE
COLUMBIA
CLEARFIELD
CENTRE
CARBON
BUTLER
LAWRENCE
UNION
MONTOUR
ARMSTRONG
INDIANA
SCHUYLKILL
SNYDER
NORTHAMPTON
BEAVER
MIFFLIN
LEHIGH
NORTHUMBERLAND
CAMBRIA
BLAIR
HUNTINGDON
JUNIATA
DAUPHIN
BERKS
BUCKS
ALLEGHENY
PERRY
LEBANON
WESTMORELAND
CUMBERLAND
LANCASTER
CHESTER
MONTGOMERY
SOMERSET
BEDFORD
YORK
FULTON
FRANKLIN
ADAMS
FAYETTE
WASHINGTON
GREENE
DELAWARE

Figure 94.

Geologic Map of Pennsylvania

PENNSYLVANIA GEOLOGICAL SURVEY

1961

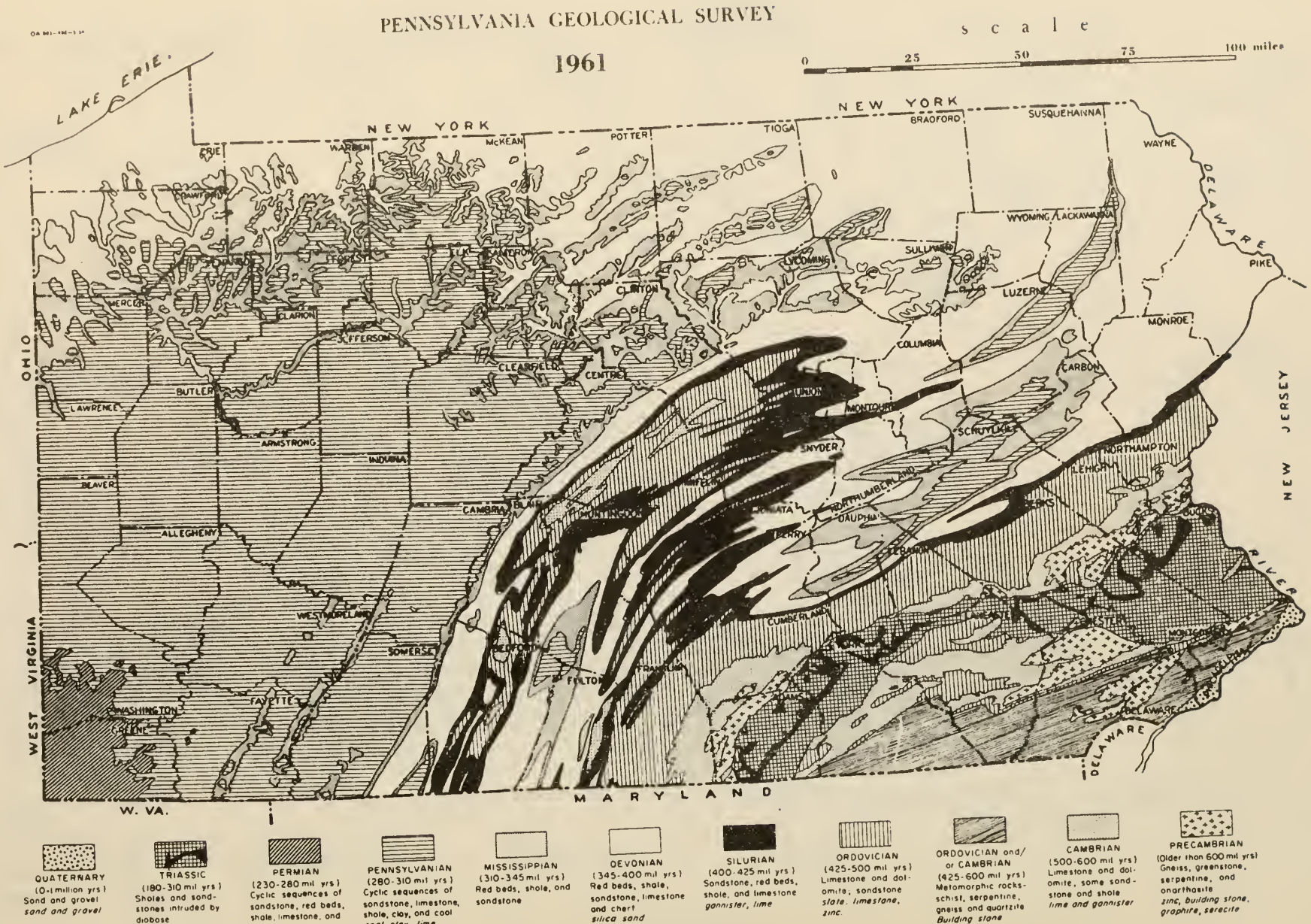


Figure 95.

Table 31 - General Geologic Section for North-Central and Western Pennsylvania with Reference to Gas Storage

SYSTEM	SERIES	GROUP or FORMATION	DESCRIPTION AND APPROXIMATE THICKNESS FEET		REMARKS ON GAS STORAGE
QUATERNARY	Recent and Pleistocene		Clays, silts, sands, gravels, boulders in surficial deposits mostly unconsolidated, comprising soil, outwash, lake deposits, stream terraces, and the glacial deposits of northwestern and northeastern Pennsylvania 0 - 200 ±		Fresh-water-bearing beds of great importance yield up to 2500 gals. per minute, not suited for gas storage because of shallow depth and lack of impervious sealing beds.
PERMIAN	Dunkard	Greene	Predominately shale, in part red, sandy shale and shaly sandstone; a few massive sandstones; several thin coal and freshwater limestone beds.	1,000	Present only in southwestern Pa. Although generally at shallow depths, one of the more massive sandstones might have storage possibilities.
		Washington	Shales, sandstones, and thin beds of coal and fresh-water limestone		
PENNSYLVANIAN		Monongahela	Shale, and fresh-water limestone, subordinate sandstone, several workable coal beds. Waynesburg coal at top and Pittsburgh coal at base. 300		A sandstone with storage possibilities should be present in these freshwater reservoirs in southwestern Pa.
		Conemaugh	Shale, in part red, and subordinate sandstone; several thin coal and fresh-water and marine limestone beds; contains Murphy, Little Dunkard and Big Dunkard sands in descending order in southwestern district. 600		In southwestern Pennsylvania some of the sandstones in these groups produce oil and gas. Locally they are used as gas storage reservoirs in stratigraphic traps. Additional reservoirs in this area should be suitable for gas storage. In the northwestern part of the State the beds produce fresh or brackish water.
		Allegheny	Shale and subordinate sandstone and limestone; several workable coal and fire clay beds. Upper Freeport coal at top and Brookville coal at base. Contains First Gas sand in lower part in southwestern district. 275		
		Pottsville	Massive medium- to coarse-grained sandstone and subordinate shale, clay and limestone. Contains First and Second Salt, and Maxton sands in southwestern district. 215		
UNCONFORMITY			An erosional unconformity bevels successively younger southerly dipping Mississippian strata in going from north to south in western Pennsylvania. In McKean County, Pottsville sandstone rests upon the Knapp formation, the lowest member of the Mississippian system; while in Fayette County, the Pottsville overlies the Mauch Chunk red shale, the highest member.		

Table 31 - General Geologic Section for North-Central and Western Pennsylvania, Cont'd:

SYSTEM	SERIES	GROUP OR FORMATION	DESCRIPTION AND APPROXIMATE THICKNESS FEET		REMARKS ON GAS STORAGE
MISSISSIPPIAN		Mauch Chank	Gray and red shale, subordinate fine-grained sandstone 0-100		Sandstones throughout the section, in the southern two-thirds of western Pennsylvania, offer several reservoirs. The Big Injun and Murrysville sandstones are being used locally as gas storage reservoirs.
		Greenbrier	Consists in descending order of limestone, a shale break, and the Loyalhanna sandy limestone 0-80		
		Pocono	Fine- to coarse-grained massive sandstone and shale, Knapp sandstone and shale at base. Contains Big Injun, Squaw, Berea, Gantz, and Murrysville sands in southwestern district. 570-900		
DEVONIAN	Upper Devonian	Conewango	Gray shale and subordinate fine- to coarse-grained light gray sandstone; red shale prominent in lower part in northern district; some purplish-red shale in middle and southwestern districts. Contains the Venango First, Second, and Third sands in the Middle district, Gantz, Fifty-foot, Upper and Lower Ninevah, Gordon and McDonald Fourth and Fifth sands in the southwestern district. Includes Chemung Formation.	3300-6000 from northwest to southeast	Except in the extreme northwestern part of the state, sandstones throughout the section offer many reservoirs. Most of the current gas storage projects utilize stratigraphic traps found in this group. Extremely important in Pittsburgh area.
		Conneaut	Gray and purplish-gray shale and sandy shale, subordinate sandstone. Contains the Bradford First or Glade sand in the northern district, Queen sand in the middle district, Bayard and Elisabeth sand in the southwestern district. Includes Portage Formation.		Sandstones in lower part bear oil and gas. Suitable stratigraphic trap type storage reservoirs present over most of western and northwestern Pennsylvania.
		Canadaway	Gray shale and sandy shale, subordinate fine- to coarse-grained light gray sandstone and fine-grained chocolate-brown sandstone. Contains the Clarendon, Cherry Grove, Bradford Second, Cooper, Bradford Third, Kane, and Haskill sands in the northern district. Speechley and Bradford sands in the southwestern district.		In the upper part of the section many sandstones bear oil and gas and are suitable reservoirs for storage. Stratigraphic traps in these sandstones are utilized for storage mostly in northwestern Pennsylvania.
		Genesee	Gray shale and sandy shale, subordinate fine-grained sandstone, dark gray and black shale.		Mostly shale and fine-grained sandstones of low porosity.

Table 31 - General Geologic Section for North-Central and Western Pennsylvania, Cont'd:

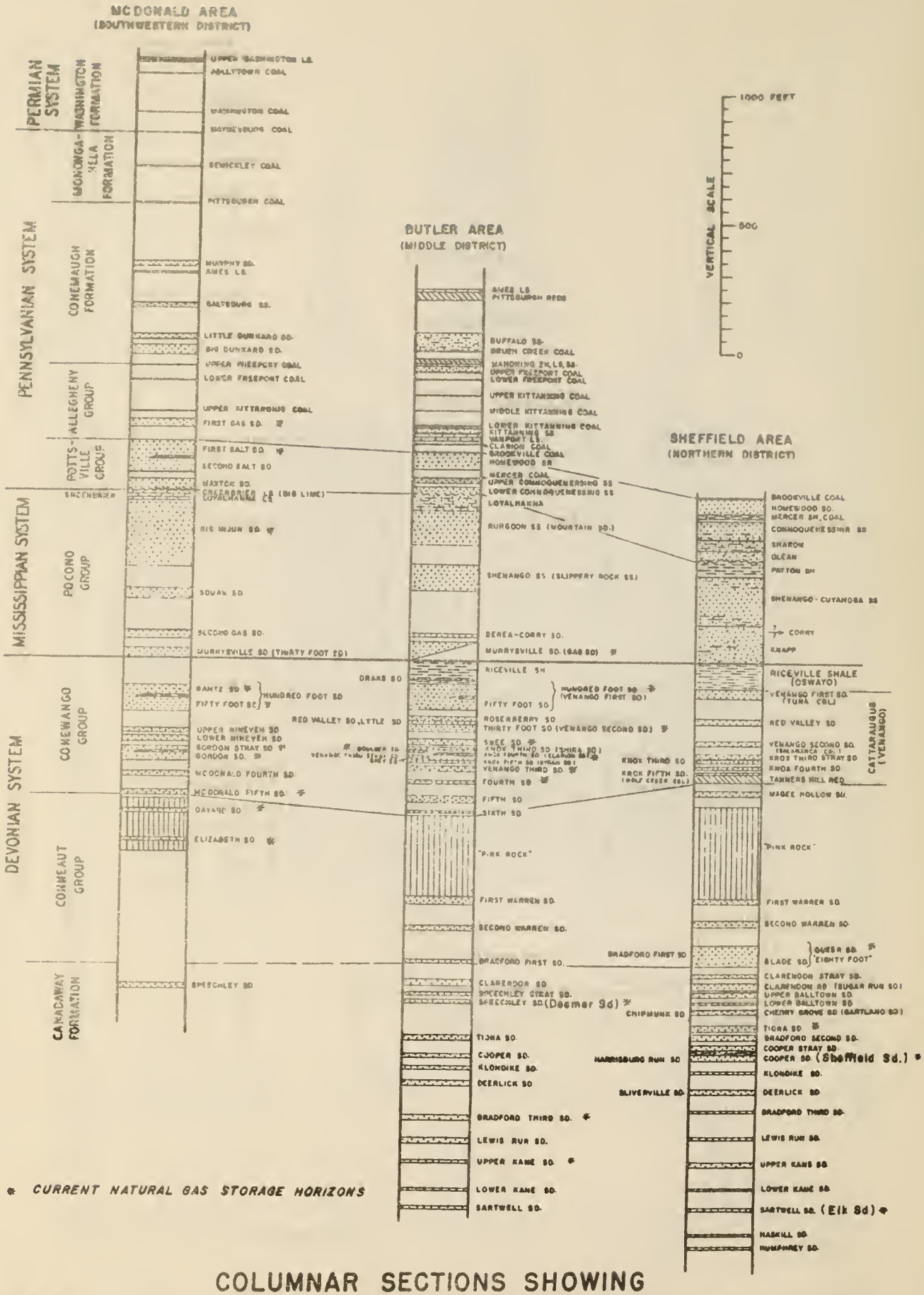
SYSTEM	SERIES	GROUP or FORMATION	DESCRIPTION AND APPROXIMATE THICKNESS FEET		REMARKS ON GAS STORAGE
DEVONIAN	Middle Devonian	Tully	Argillaceous limestone 0-150		Mostly shale and argillaceous limestone
		Hamilton	Dark gray and black shale, in part calcareous 100-2000		
		Onondaga	Cherty limestone and chert, subordinate dark, silty, shaly and glauconitic beds. Source of gas in fields in Clearfield, Indiana, Westmoreland and Fayette Counties. 8-290		Has future storage possibilities. Is gas productive in fracture porosity.
	Lower Devonian	Oriskany	Medium-grained quartz sandstone, locally calcareous, Source of gas from north-central to southwestern Pennsylvania, and in Erie County. 0-175		Gas productive in numerous areas, deeply buried, states most important storage horizon
		Helderberg	Non-magnesian, in part cherty, frequesntly very fossiliferous limestone. 0-350		Of little interest
SILURIAN	Upper Silurian or Cayugan	Bass Island or Keyser	Argillaceous dolomitic limestone 20-450		Of little interest
		Salina	Interbedded, dense, argillaceous, magnesian limestone, gray shales and clays for the most part either calcareous or dolomitic. Numerous interbedded layers of anhydrite and salt. Small gas production in McCance field, Westmoreland County. 450-2000		Thick salt deposits suited for liquid storage in washed-out cavities. Natural gas storage not probable at this time.
	Middle Silurian or Niagaran	Lockport	Very fine, crystalline, brownish-gray to very dark grayish brown relatively pure dolomite. A salt-water zone frequently present. Small gas production in Mercer County. 240-320		Of little interest, Possible reservoir in salt-water zone
		Clinton	Shale, dolomitic shale, and subordinate dolomite. 100-300		
	Lower Silurian or Albion	Grimsby	Red and gray sandstone and shale. Gas and minor oil production in northwestern Pennsylvania	70-220	Of interest in extreme northwestern Pa. where beds are about 3500 feet in depth. One storage project utilizing the Medina section
		Cabot Head	Gray shale and subordinate very fine-grained light-gray sandstone		
		Whirlpool	Fine-grained light-gray sandstone. Minor gas production in northwestern Pennsylvania.		

Table 31 - General Geologic Section for North-Central and Western Pennsylvania. Cont'd:

SYSTEM	SERIES	GROUP or FORMATION	DESCRIPTION and APPROXIMATE THICKNESS FEET		REMARKS ON GAS STORAGE
ORDOVICIAN	Upper Ordovician or Cincinnatian	Queenston	Red shale, in part silty and sandy. 850-1200		Of little interest. Mostly fine-grained sandstones and shales.
		Oswego	Very fine-grained gray sandstone. 0-60		
		Reedsville	Gray shale. 700-800		
		Utica	Black shale. 100-300		
	Middle Ordovician or Champlainian (and possibly upper Canadian)	Trenton	Fine to very fine crystalline, argillaceous and fossiliferous, brownish gray limestone, with interbedded dark gray to grayish black calcareous shale. At base is usually a 20' to 50' zone with a little interbedded light gray bentonite or silty limestone. In Erie Co., top 10' to 15' is dolomitic. Thickness increases from 250' to 440' in north to northwesterly direction. Greatest thickness in Erie and northern Warren Counties. 200 to 440	650 - 800	Of little interest due to extreme depths over most of western Pennsylvania. No commercial production found to date in these beds. Possible storage in mined cavities.
		Black River and Chazy ?	Dense to very fine crystalline, occasionally fossiliferous, light brownish to brownish gray limestone. In northwestern Pa. the lower part contains some interbedded dolomite and dolomitic limestone. Thickens from 275' to 500' in southerly direction. Greatest thickness in Northern Butler and southern Mercer County. 200 to 350		
		Chazy ? and Upper Beekmantown?	Silty and sandy dolomite and limestone in upper part; dolomitic shale and silty shale in lower part, with a dolomitic sandstone commonly found at base. Thickness 30' to 150'; axis of greatest thickening in northeast-southwest direction through southern Warren Co., northwestern Venango Co., and southwestern Crawford Co., and northern Mercer Co.		
	Unconformity		Approximately 4500 feet of Lower Ordovician strata present in central Pa., are missing in western Pa.		

Table 31 - General Geologic Section for North-Central and Western Pennsylvania, Concluded

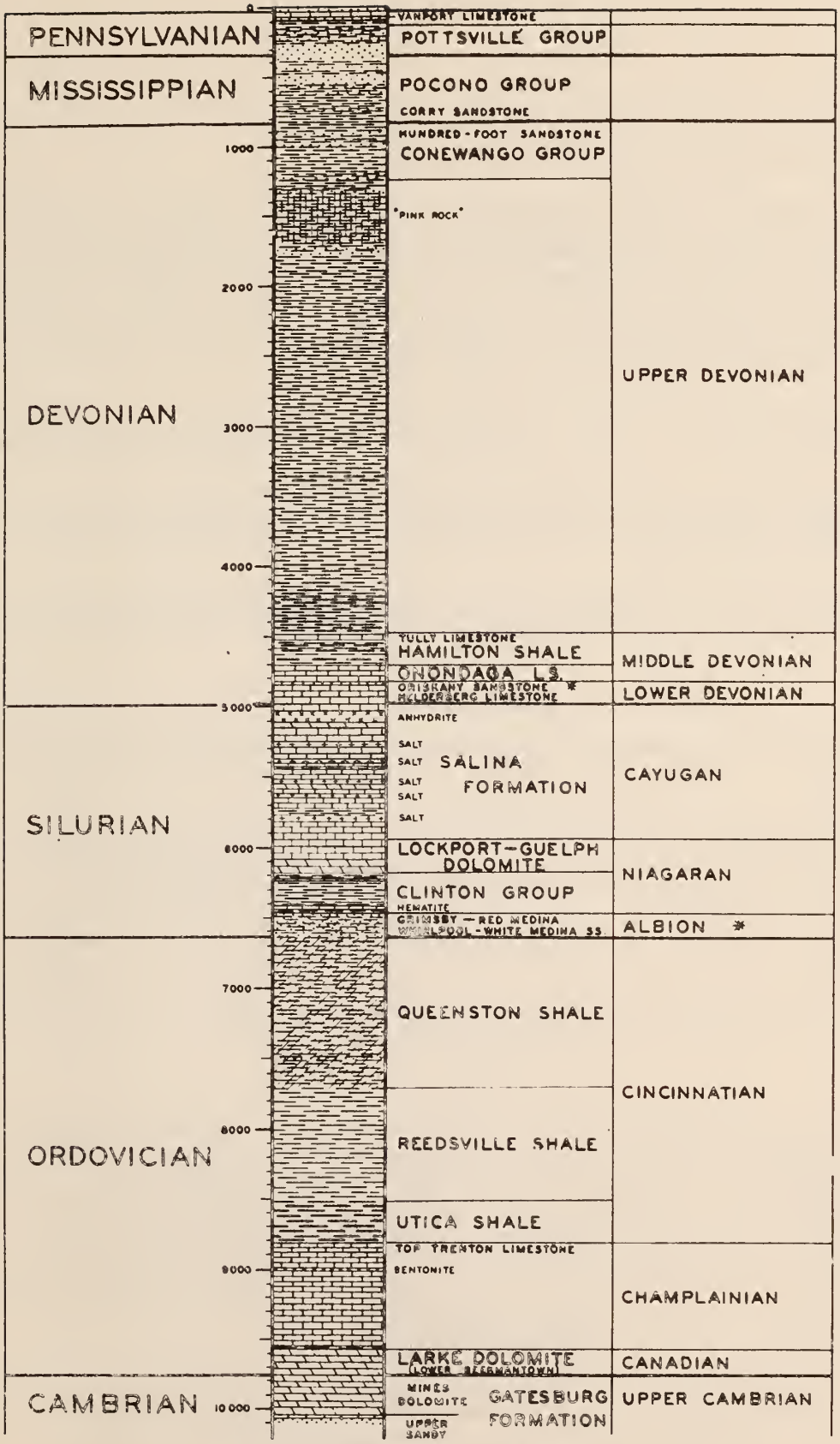
SYSTEM	SERIES	GROUP or FORMATION	DESCRIPTION and APPROXIMATE THICKNESS FEET	REMARKS ON GAS STORAGE
	Lower Ordovician or Canadian	Lower Beekmantown	Fine to medium crystalline, siliceous, light gray dolomite. Thickens in southerly and easterly direction from northwest corner of Pennsylvania. 0-190	Same as Middle Ordovician
CAMBRIAN	Upper Cambrian	Gatesburg	Upper member- Dolomitic sandstone and/or fine to medium crystalline, sandy dolomite, light brownish gray. 60 to 200 Middle member- Fine to medium crystalline, sandy, oolitic to mottled, brownish to light brownish gray dolomite, with dolomitic limestone at base. 200 Lower member- Fine to medium grained sandstone, with interbedded sandy dolomite and a little gray shale. 100	Where penetrated the Gatesburg Sandstone has produced salt water and on occasions had shows of gas. Although at great depth, this horizon might be of interest in the future.
		Warrior: Eau Claire	Dark brownish to brownish gray dolomite, in part sandy and oolitic; some interbedded gray shale and shaly dolomite especially near top. 400 ±	
		Warrior: Mt. Simon	Light- to very light-gray sandstone, fine to coarse grained, dolomitic to siliceous. 100±	
UNCONFORMITY			Approximately 9000' of Lower & Middle Cambrian strata present in South Mountain area of south-central Pa. are absent from western and north-central Pa.	Possible storage in mined cavities
PRECAMBRIAN			Igneous and/or metamorphic rocks Revised by Walter R. Wagner, 1960, after C. R. Fettke, 1956, adapted for this report by William S. Lytle, 1960	Possible storage in mined cavities.



COLUMNAR SECTIONS SHOWING
STRATIGRAPHIC POSITIONS OF OIL AND GAS SANDS
OF WESTERN PENNSYLVANIA

JOHN M. BERGSTEN, 1957

Figure 96.



COLUMNAR SECTION
WESTERN PENNSYLVANIA
OBTAINED IN JESSIE G. HOCKENBERRY WELL NO. 1
MANUFACTURERS LIGHT & HEAT COMPANY
MERCER TOWNSHIP, BUTLER COUNTY, PA.

* CURRENT NATURAL GAS STORAGE HORIZONS

CHAS R FETTKE 1953

Figure 97.

anticlinal traps or up dip pinchouts. More gas is stored in the Oriskany than in any other horizon. Other suitable reservoirs on anticlinal structures are yet to be developed.

The Salina Group of Upper Silurian age underlies the entire plateau area of north-central and western Pennsylvania. The Salina is composed of beds of rock salt, individual salt layers ranging from less than 5 feet to nearly 200 feet in thickness. Salt beds sometimes possess combined thicknesses of over 650 feet and occupy intervals in the Salina ranging from less than 50 feet to over 1,200 feet. The uppermost salt bed is encountered at a depth of about 2,000 feet in Erie County and approximately 10,000 feet in the synclinal areas of the Allegheny Mountains Section. The thick salt deposits are suited for liquid storage in washed-out cavities. The beds are generally at a depth greater than other suitable rocks in the same area. There is no reason to consider this group for gas storage at this time.

The Medina Sandstone of Lower Silurian age is of interest in extreme northwestern Pennsylvania where the beds are about 3,500 feet in depth. A storage pool in Erie County utilizes the Medina Sandstone.

The Gatesburg Sandstone of Upper Cambrian age might become important as a storage reservoir. Although at great depth, it has porosity and permeability as shown by its production of saltwater when penetrated. Possibly the Gatesburg will be of interest in the future. This horizon has been used in Missouri as a gas storage reservoir in an aquifer.

The other Ordovician and Cambrian rocks and the Precambrian rocks are of little interest at the present. In large market areas, man-made cavities in these rocks might be used for storage of natural gas.

Unconformities

In the Paleozoic section in Pennsylvania there are three unconformities occurring between the Pennsylvanian and the Mississippian systems, the Devonian and Silurian systems, and the Middle and Lower Ordovician series.

The Pottsville Sandstone of the Pennsylvania system in northwestern Pennsylvania rests upon the Knapp Formation, the basal formation of the Mississippian system, while in southwestern Pennsylvania the Pottsville overlies the Mauch Chunk Shale, the youngest formation of the Mississippian.

Except for the Coastal Plain and Triassic sediments, all rocks southeast of the Ridge and Valley Section are of Ordovician age or older.

A section of the Lower Ordovician, which is represented by approximately 4,500 feet of strata in central Pennsylvania, is missing in deep wells in westernmost Pennsylvania.

Structure

Pennsylvania lies in the Appalachian Basin, a broad asymmetrical structural trough or synclinorium. The basin is modified by a series of minor folds with axes trending northeast and southwest approximately parallel with the long axis of the trough. On the steep southeast limb, these consist of strong, well defined anticlines and synclines. Northwestward the intensity of the folding diminishes so that the folds become less prominent in the central part of the basin and disappear in the northwest part. The northwesternmost major fold is the Chestnut Ridge Anticline extending from West Virginia to the northeast, diagonally across Pennsylvania to the New York State line. This anticline marks the western boundary of the Allegheny Mountain Section. The rocks in the Plateaus Province dip to the south and southeast at 25 feet to 35 feet to the mile except where minor folding has taken place. Thus rocks at the surface in Erie County are 3,000 feet below the earth's surface in southwestern Pennsylvania.

It has been revealed by deep drilling that the folds are much more complex structurally than had been anticipated by surface mapping. The domes along the anticlinal axis at the Oriskany horizon have been complexly and extensively modified by the commonly northwest-dipping reverse faults.

Gas Storage Projects in Pennsylvania

Pennsylvania had 61 active natural gas storage pools or fields, both shallow and deep, at the close of 1959 (table 32). The natural gas is stored in depleted gas pools in rocks from Silurian to Pennsylvanian

Table 32 - Natural Gas Storage Projects in Pennsylvania

Map No.	County and Project	Township	Gas Utility	Discovery Year	Wells	Acres of Storage Formation	Acres Controlled	Average Production Depth (ft.)	Average Sand Thickness (ft.)	Date of First Injection	Capacity MMcf Working Gas	Capacity MMcf Cushion Gas	Capacity MMcf Total Reservoir	Storage Formation	Maximum Storage Pressure (psi)
	ALLEGHENY														
1	Gamble-Hayden	Forward	Peoples Nat.Gas Co.	1929	14	600	1,441	2,775	20	1943	1,100	1,200	2,300	Bayard	1,000
2	Mt. Royal	Shaler	Peoples Nat.Gas Co.	1917	7	100	424	1,656	20	1949	225	275	500	Thirty Foot	400
3	Murrysville	Plum	Peoples Nat.Gas Co.	1916	16	350	1,453	1,975	30 pay	1939	1,500	1,600	3,100	Hundred Foot	1,000
4	Tarentum Stone & Coal	Frazer	T.W.Phillips Gas & Oil Co.		1	10	79	1,557	20 net	1948	-	-	-	Boulder	53
5	Tepe	Jafferson	Equitable Gas Co.	1928	6	470	996	2,280	5 net	1936	1,380	320	1,700	Fifth	1,000
	ALLEGHENY and WASHINGTON														
6	Runola	Forward, Union	Equitable Gas Co.	1895	28	1,980	3,028	2,040	12 net	1937	4,220	1,280	5,500	Gantz	750
	ARMSTRONG and INDIANA														
7	South Bend	South Bend, Armstrong & Plum Creek	New York State Nat. Gas Corp.	1923	70	3,300	10,388	1,600	100	1951	6,600	10,500	17,100	Hundred Foot	630
	BUTLER														
8	Hughes	Buffalo	T.W.Phillips Gas & Oil Co.		1	12	85	2,020	13 net	1955	-	-	-	Fifth	815
9	Neubert	Jefferson	Saxonburg Ht. & Lt. Co.	1920	1	25	40	1,400	30 net	1953	5	2	7	Murraysville	140
10	Portman	Summit	T.W.Phillips Gas & Oil Co.		2	30	151	1,581	24 net	1942	-	-	-	Fifth	407
11	Saxonburg	Jefferson	Saxonburg Ht. & Lt. Co.	1947	4	115	230	1,800	30	1954	20	10	30	Venango Fourth	40
	CLARION														
12	Truittsburg	Red Bank	Peoples Nat. Gas Co.	1925	24	750	3,002	1,562	20	1949	2,100	1,500	3,600	Bayard	900
	CLINTON and POTTER														
13	Leidy	East Keating, Grove, Leidy, Stewardson	New York State Nat. Gas Corp.(Operator) Transcontinental Gas Pipeline Corp. Texas Eastern Transmission Co. (operator)	1950	71	15,120	54,263	6,050	30	1959	54,000	41,000	95,000	Oriskany	4,000

Table 32 - Natural Gas Storage Projects in Pennsylvania Cont'd.

Map No.	County and Project	Township	Gas Utility	Discovery Year	Wells	Acres of Storage Formation	Acres Controlled	Average Production Depth (ft.)	Average Sand Thickness (ft.)	Date of First Injection	Working Gas	Capacity Mcf Cushion Gas	Total Reservoir	Storage Formation	Maximum Storage Pressure (psi)	
	ELK															
14	Belmouth		United Nat.Gas Co.	1915	22	-	-	1,900	10	1938	450*	450	900	Cooper	700	Original RP
15	Boone Mt.		United Nat.Gas Co.	1901	31	-	-	1,230	45	1947	800*	650	1,450	Fifth Venango	500	Original RP
16	Mohan Run		United Nat.Gas Co.	1924	19	-	-	2,360	20	1949	70*	0	70	Elk	635	Original RP
17	Owls Nest	Highland & Spring Creek	Pennsylvania Gas Co.	1908	38	987	-	1,930	29	1949	900	900	1,800	Tions	650	(three small projects)
18	St. Marys		United Nat.Gas Co.	1916	15	-	-	1,330	40	1936	180*	100	280	Fifth Venango	590	Original RP
	ERIE															
19	Corry	Wayne	Pennsylvania Gas Co.	1947	10	832	-	4,520	13	1955	300	300	600	Medina	1,200	
20	Meads (Summit)	Summit	Pennsylvania Gas Co.	1946	49	2,147	-	2,350	10	1959	2,800	1,900	4,700	Oriskany	800	
	FOREST															
21	Duhring	Jenks	Pennsylvania Gas Co.	1941	6	56	-	930	31	1947	150	100	250	Deamer	225	
	GREENE															
22	Holbrook	Center	Manufacturers Lt. & Ht. Co.	1920	18	1,316	4,320	2,850	25	1950	700	500	1,200	Hundred Foot	1,000	
23	Hunters Cave	Center & Morris	Equitable Gas Co.	1917	16	1,694	4,162	2,172	10 net	1942	1,880	920	2,800	Big Injun	950	
24	Kirby	Perry & Whiteley	Equitable Gas Co.	1926	23	5,423	7,453	(2,681 (3,082	6 net) 4 net)	1945	1,975	925	2,900	(Gantz & (Fifth	950	
25	Swartz	Morris & Washington	Equitable Gas Co.	1922	6	523	1,126	2,750	14 net	1949	1,504	136	1,640	50 Foot	1,000	
	GREEN and WASHINGTON															
26	Pratt	Morgan, Washington, & W. Bethlehem	Equitable Gas Co.	1902	45	5,567	11,275	(2,498 (2,845	6 net) 11 net)	1947	3,890	1,320	5,210	(50 Foot (Fifth	650	
27	Haard	Richhill & W. Finley	Manufacturers Lt. & Ht. Co.	1907	57	3,487	10,188	2,510	240, 12, 15, 13, 9	1943	3,500	5,800	9,300	(Big Injun, 50 Foot; 30 (Foot, Gordon Stray, (& Gordon	900	
28	Majorsville (partly in W.Va.)	Richhill & W. Finley	Manufacturers Lt. & Ht. Co.	1905	177	8,736	23,603	(1,370 shallow) (2,510 deep)	(16, 23, 290,) (13, 15, 13, 9,) (8)	1937	10,500	19,500	30,000	(Gas Sd, Salt Sd, Big Injun (100 Foot; 30 Foot; Gordon) (Stray, Gordon, Fifth)	600 (shallow) 900 (deep)	
	INDIANA															
29	Alabran	W.Mahoning & W.Mahoning	T.W.Phillips Gas & Oil Co.		10	294	883	2,062	28 net	1955	-	-	-	(Murraysville, 100 Foot) (Venango Third, Sheffield, Bradford)	252	
30	Kinter	S.Mahoning & E.Mahoning & Rayne	T.W.Phillips Gas & Oil Co.		14	240	1,359	1,740	35 net	1949	-	-	-	(Murraysville, 100 Foot; 30) (Foot; Boulder; Venango Third;) (Bradford, Vane)	312	

Table 32 - Natural Gas Storage Projects in Pennsylvania, cont'd.

Map No.	County and Project	Township	Gas Utility	Discovery Year	Wells	Acres of Storage Formation	Acres Controlled	Average Production Depth (ft.)	Average Sand Thickness (ft.)	Date of First Injection	Capacity MMcf Working Gas	Capacity MMcf Cushion Gas	Capacity MMcf Total Reservoir	Storage Formation	Maximum Storage Pressure (psi)	
	JEFFERSON															
31	Bullers		United Nat.Gas.Co.	1922	9	-	-	810	15	1950	40*	10	50	U.Murraysville	260	Original RP
32	Galbraith		United Nat.Gas Co.	1917	36	-	-	2,870	25	1937	940*	660	1,600	1st Sheffield	620	Original RP
33	Towa	Knox & Pine Creek	Manufacturers Lt. & Ht. Co.	1909	4	622	1,359	1,375	16	1945	125	175	300	Elizabeth	550	
34	Markle		United Nat.Gas Co.	1921	8	-	-	1,590	15	1938	100*	240	340	Fifth Venango	625	Original RP
35	Mundarf	Warren	Manufacturers Lt. & Ht. Co.	1926	1	92	678	2,400	22	1943	50	0	50	Speechley	400	
36	Sprankle	Perry & Young	T.W.Phillips Gas & Oil Co.		12	198	1,106	1,588	30 net	1954	-	-	-	Murraysville, Hundred Foot; 30 Foot, Snee Boulder, Bradford	250	
	McKEAN															
37	Keelor	Hamilton & Wetmore	Pennsylvania Gas Co.	1906	30	1,607	-	1,930	31	1946	1,400	1,400	2,800	Cooper	500	
38	Meade Run	Wetmore	Kane Gas Lt. & Ht. Co.	1900	14	195	2,500	800	15	1942	57	60	117	Clarion	350	
39	Swede Hill	Hamilton	Pennsylvania Gas Co	1903	28	956	-	1,810	71	1950	500	500	1,000	Tiona	600	
40	Wellandorf		United Nat.Gas Co.	1904	19	-	-	1,160	25	1929	265*	615	880	Fifth Venango	450	Original RP
	McKEAN & WARREN															
41	East Branch "A"	Hamilton, Wetmore & Sheffield	Pennsylvania Gas Co.	1888	75	4,275	-	1,960	25	1948	1,100	1,500	2,600	Cooper	240	
42	East Branch "B"	Hamilton & Sheffield	Pennsylvania Gas Co.	1889	82	2,427	-	1,950	63	1953	3,600	1.900	5,500	Cooper	350	
	MERCER & VENANGO															
43	Handarson		United Nat.Gas Co.	1899	93	-	-	910	35	1934	1,600*	1,150	2,750	First Venango Third Venango	300	Original RP Est.
	POTTER															
44	Harrison (partly in N.Y.)	Bingham, Harrison & Brookfield	New York State Nat. Gas Co.	1934	55	10,800	29,380	4,989	27	1953	19,680	13,120	32,800	Oriskany	2,000	
45	Hebron		United Nat.Gas Co. & Tenn. Gas Transmission Co.	1931	53	est.3,500	est.7,500	5,160	20	1953	22,500	23,800	46,300	Oriskany	2,200	
46	Sharon	Sharon & Oswayo	New York State Nat. Gas Co.	1938	14	1,333	3,955	4,827	13	1948	1,900	4,200	6,100	Oriskany	860	

Table 32 - Natural Gas Storage Projects in Pennsylvania, cont'd.

Map No.	County and Project	Township	Gas Utility	Discovery Year	Wells	Acres of Storage Formation	Acres Controlled	Average Production Depth (ft.)	Average Sand Thickness (ft.)	Date of First Injection	Working Gas	Capacity M'cf Cushion Gas	Total Reservoir	Storage Formation	Maximum Storage Pressure (psi)
	TIOGA														
47	Palmer	Farmington	North Penn Gas Co.	(1930	19	-	8,745	4,000	10	1935)	8,200	1,800	10,000	Oriskany	1,500
48	Meeker	Farmington	North Penn Gas Co.	(							4,800	200	5,000	Oriskany	1,500
49	Sabinsville	Clymer, Westfield & Chatham	New York State Nat. Gas Co.	1935	28	6,800	15,407	4,600	15	1951	15,450	18,000	33,450	Oriskany	2,200
50	Boom	Lawrence & Farmington	New York State Nat. Gas Co.	1930	34	5,116	9,142	4,000	35	1940	20,800	14,000	34,800	Oriskany	1,500
	WARREN														
51	Deerlick	Sheffield	Pennsylvania Gas Co.	1888	30	1,660	-	1,390	13	1950	100	0	100	Tiona	100
	WARREN & FOREST														
52	Queen		United Nat.Gas Co.	1889	22	-	-	1,200	80	1920	150*	300	450	Queen	400 Original RP Est.
	WASHINGTON														
53	Colvin	Fallowfield	Peooles Nat.Gas Co.	1924	9	530	1,176	2,300	30	1943	800	1,500	2,300	Murraysville	685
54	Cross Creek	Jefferson	Manufacturers Lt. & Ht. Co.	1901	16	1,855	5,296	1,950	12	1937	125	900	1,025	Hundred Foot	200
55	Donegal	Donegal	Manufacturers Lt. & Ht. Co.	1907	91	3,563	15,433	2,650	12	1940	3,400	4,000	7,400	Gordon Stray	1,000
56	Finleyville	Union	Equitable Gas Co.	1927	4	221	576	2,621	8 net	1934	487	73	560	Fifth	1,000
	WESTMORELAND														
57	Irwin	North Huntington	Manufacturers Lt. & Ht. Co.	1917	3	407	14	548	24	1942	25	325	350	Elizabeth	225
58	Oakford	Salem, Penn & Hempfield	New York State Nat. Gas Co.	1885) 1907)	269	13,548	34,562	(1,400 (2,200	100 60	1951 1951	51,408 8,592	36,850 13,908	88,258 22,500	Murraysville Fifth	267 1,143
59	Patton	Rostraver	Peoples Nat.Gas Co.	1924	1	70	300	2,122	25	1948	75	75	150	Murraysville	600
60	Trafford	Penn	Duquesne Nat Gas Co.	1923	5	458	1,000	2,250	35	1948	150	50	200	Fifth	300
61	Webster	Rostraver	Peoples Nat.Gas Co.	1923	5	600	1,993	2,179	30	1945	540	600	1,140	Murraysville	600

*Data obtained from Oil & Gas Journal

in age and from 1,000 feet to 6,000 feet in depth. The storage pools occupy stratigraphic rather than structural traps in Pennsylvanian, Mississippian, Upper Devonian and Lower Silurian (Medina) strata. In contrast, the gas stored in the Oriskany Sandstone (Lower Devonian in age) pools occupies structural traps consisting of elongated domes along the prominent anticlines.

The pool underlying the most acreage is the Leidy Pool in Clinton County with 15,120 acres and a total reservoir capacity of 95,000,000 Mcf.

The Oakford Storage Field covers 13,548 acres and has a reservoir capacity of 110,758,000 Mcf. The Oakford Storage Field is in Westmoreland County in the southwestern portion of the state (figure 92, field 58) along the eastern flank of development on the Grapeville Anticline, a minor fo in the Appalachian Plateaus Province. The two principal producing sands in the area are the Murrysville and Fifth sands which are the gas storage reservoirs in the field.

The Murrysville is the shallower of the two sands, being 1,400 feet below the surface. It is about 100 feet thick with an average pay thickness of approximately 50 feet. The accumulation of gas in the Murrysville sand was due partly to structure. Gas accumulated in the top of the dome, limited along the axis of the anticline by saddles on each end. The low portion of the structure is effectively sealed by salt water. This sand is very coarse and pebbly and has a porosity of about 20%.

Depth to the Fifth sand averages 2,200 feet. It is about 60 feet thick and has 20 feet of productive sand with an average porosity of 13%. The trap in the Fifth sand is due to porosity being sealed on its boundary by tight sand. The large number of wells drilled in this area has established the boundaries of both pools.

The first wells were drilled in the Murrysville sand in Oakford in 1887. The rock pressure was 600 psi plus, and well flows ranged from 10,000 Mcf to 40,000 Mcf per day. Fifth sand production was discovered in 1907 with an initial rock pressure of 1,100 psi and open flows from 20,000 Mcf to 30,000 Mcf per day.

The Murrysville sand has a working capacity of 51,408,000 Mcf and the Fifth sand 8,952,000 Mcf, making a total working capacity of 60,000,000 Mcf.

Natural gas storage figures for the year 1960 as published by the AGA show Pennsylvania as the ranking state in all phases of gas storage: the maximum gas in storage, 485,000,000 Mcf; total input, 227,000,000 Mcf; maximum day output, 2,859,000 Mcf; total output, 177,000,000 Mcf; and ultimate capacity, 497,000,000 Mcf.

Regulation of Underground Gas Storage Pools

The Pennsylvania Gas Operations, Well-Drilling, Petroleum and Coal Mining Act of 1955, known as Act 225, relates to coal mining, well operations, the underground storage of gas except in storage reservoirs excavated in rock formations specifically for storage purposes, and the safety of personnel and facilities employed therein.

Article 3 of the above act deals specifically with "Regulation of Underground Gas Storage Pools in Certain Areas." Section 301 of this article is concerned with the filing of maps and data by persons operating or proposing to operate gas storage reservoirs within three thousand to ten thousand linear feet of an operating coal mine which is operating in a coal seam that extends over the storage reservoir or the reservoir protective area. The requirements of this section do not apply to the operator of an underground gas storage reservoir if the reservoir is located more than ten thousand linear feet from an operating coal mine and provided that a location map of the gas storage reservoir is filed with the Oil and Gas Division carrying out the provisions of this act. Section 302 requires the filing of maps and data by persons operating coal mines. Section 303 concerns notices to be sent to the Oil and Gas Division by persons operating coal mines within 2,000 linear feet of a gas storage reservoir. Section 304 states the obligations of persons operating storage reservoirs which underly or are within two thousand linear feet of an operating coal mine which is operating in a coal seam that extends over the storage reservoir or the reservoir protective area. Section 305 has to do with the inspection of facilities and records, the reliance on the most recent maps for locations, and the burden of proving the accuracy of the map or data. Section 306 exempts certain types of coal mines from the provisions of the act, prohibits the injection of

gas for storage purposes in any workable coal seam, and makes sure that Article 3 is not construed so as to prohibit the original extraction of natural gas, crude oil or coal.

Article 4 of Act 225 deals with "Eminent Domain." Section 401 of this article provides that the right of eminent domain shall not be exercised to acquire for the purpose of gas storage any geological stratum unless the original recoverable oil or gas reserve therein has been depleted at least 80%, until the condemnor has acquired at least 75% of the area of the proposed reservoir. The right of eminent domain cannot be exercised in any area where gas is already being stored. The owner of nonstorage strata in a storage area may drill wells for the purpose of producing oil or gas from any stratum above or below the storage stratum so long as the storage stratum is being adequately protected to prevent the escape of the stored gas.

Conclusions

The completion of pipelines carrying western gas to the eastern states (figure 93), the depletion of our own reserves, and the great market demand for natural gas has stepped up the development of natural gas storage pools in Pennsylvania. Several storage projects are being developed, but more are needed. In western Pennsylvania, geologic conditions are favorable for the economical storage of natural gas in porous rocks of Pennsylvanian to Silurian in age. Although most of the same rocks occur in the northeastern part of the state, suitable reservoir rocks have not yet been found in this area. Nor have suitable traps been found in the southeastern part of the state. At present the only solution in the southeastern section is man-made cavities for the storage of gas.

Where large population centers and industries are located in the western part of the state we also find natural gas reservoirs at comparatively shallow depths. There are a number of oil and gas reservoirs in this area which are possible gas storage pools. The conversion of some of the present Oriskany gas pools to storage pools will increase the storage facilities considerably.

Pennsylvania has numerous coal mines. As the development of gas storage in coal mines progresses, some of Pennsylvania's mines might meet the requirements.

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RHODE ISLAND

Alonzo W. Quinn, Chairman
Department of Geology, Brown University

The storage of gas in porous rocks has come to have great economic importance in several states, chiefly petroleum-producing states. However, none of the bedrock of Rhode Island is porous enough to be suitable for the storage of natural gas, and no natural gas or oil has been produced in Rhode Island. Therefore, any underground storage of gas here will have to be in cavities excavated in the rock.

The eastern part of the state is within the Narragansett Basin of Pennsylvanian sedimentary rocks. There are also two small areas of Pennsylvanian rocks a few miles west of the Narragansett Basin. These Pennsylvanian rocks are interbedded sandstone, shale, conglomerate, and meta-anthracite. Extreme irregularity and variability are characteristic of these rocks. The shaly rocks are easy to excavate but in places are graphitic and weak. Joints and other fractures are abundant in all of these rocks.

The conglomerate and sandstone are generally very strong, not greatly different from granite in physical characteristics.

The other rocks of Rhode Island are chiefly granite, granite gneiss, and various metamorphic rocks. Most of the granite and granite gneiss is strong and sound. Excavation is probably about average in difficulty for granite; joints and other fractures are also about average for granite. The metamorphic rocks include chiefly quartz-mica schist, greenstone, quartzite, and marble. The schist and greenstone are variably slabby and much fractured. The quartzite is strong and sound, but somewhat fractured in places. Most of the marble has been or is being worked for agricultural limestone, plaster, etc.

There are very few if any underground excavations that would be suitable for gas storage. Large quarries are chiefly in granite but also in marble. Most of these are open pit operations, although the Sullivan granite quarry at Bradford extends underground several hundred feet. Two rather extensive underground mines in anthracite have been developed. The Portsmouth mines have been closed for almost forty years. Very little is known about the extent of these openings. The Cranston mine has been closed for about two years, but it is near a housing development. This was mapped in 1945, and the map was published in Report of Investigations 4276 of the U. S. Bureau of Mines. Considerable mining was done after 1945, but there is no published map of the extensions.

The distribution of different kinds of bedrock in Rhode Island is shown in a general way by the map in Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island, U. S. Geological Survey Bulletin, 597. Much greater detail is shown by the most recent geological quadrangle maps of the U. S. Geological Survey.

SOUTH CAROLINA

H. S. Johnson, Jr., Chief
Division of Geology
South Carolina State Development Board

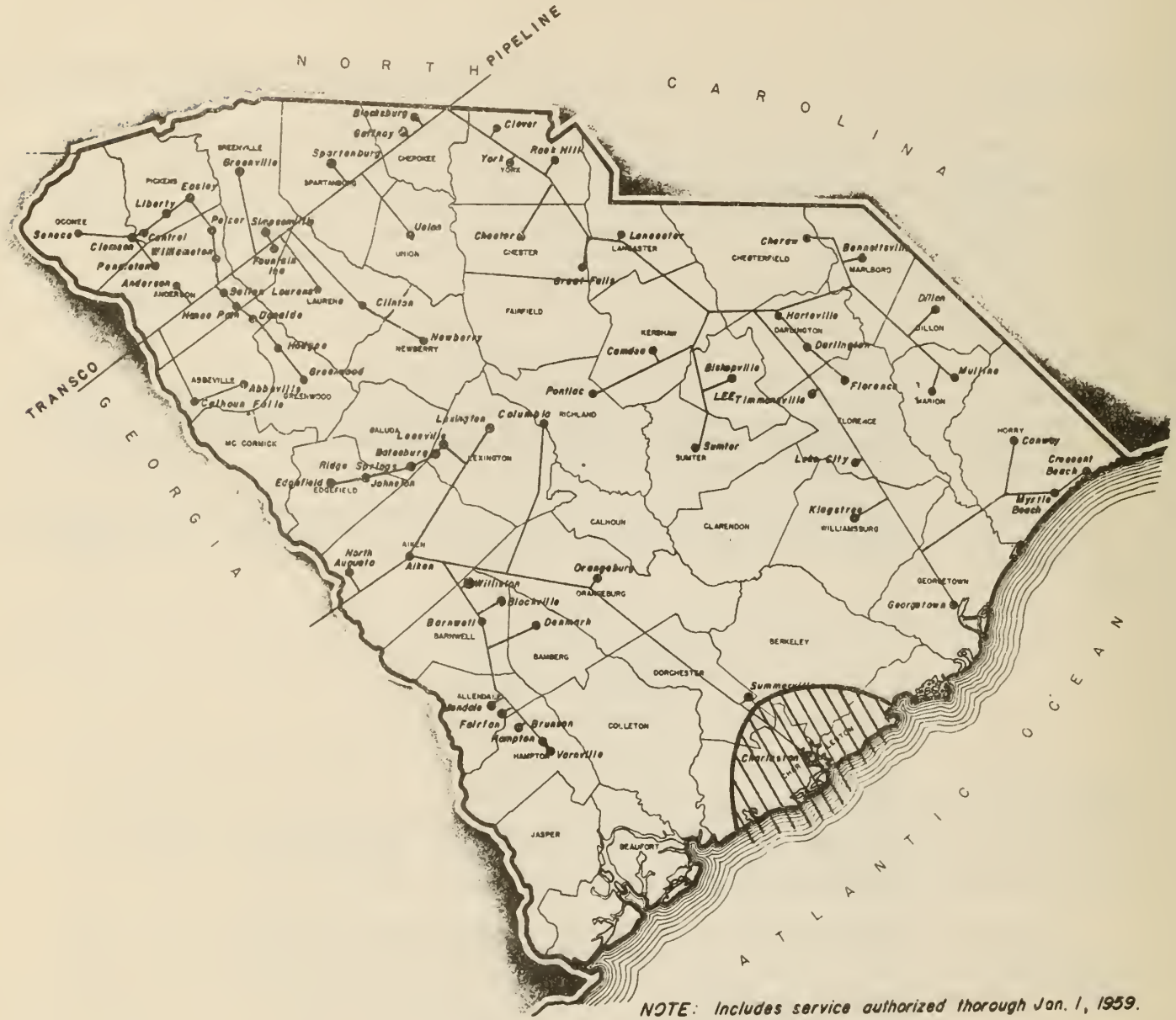
As yet there are no known oil or gas fields in South Carolina. All natural gas used in the state is brought in by pipeline from sources in Louisiana and Texas. Figure 98 shows gas pipeline facilities in South Carolina as of January 1, 1959. Potentially the state may also be supplied to some extent by barge or tanker through the ports of Beaufort, Charleston, and Georgetown. There is also a possibility that the current increased interest in exploration for oil and gas along the Atlantic Coast may lead to discoveries of natural gas in the coastal area of South Carolina or adjacent states.

Underground storage for natural gas has not been developed in South Carolina to date, but considerable thought has been given to the feasibility of it. Geologically there are three possibilities: caverns in granite and gneiss of the Piedmont; caverns in the Cooper marl (Eocene-Oligocene) near Charleston; water-sand storage in the lower Coastal Plain.

Caverns in Granite and Gneiss

The northwestern half of South Carolina is part of the Piedmont Province and is underlain by a complex terrane of igneous and metamorphic rocks. The metamorphic rocks range from phyllite, fine-grained sericite and mica schist to high rank schists and gneisses containing garnet, staurolite, kyanite, and sillimanite. Large areas of relatively homogeneous granite, granite gneiss, and gabbro are common at many places in the Piedmont. Of particular interest are granite and granite gneiss bodies underlying or immediately adjacent to the Transco gas pipeline near Belton in Anderson County and Fountain Inn in Greenville County. Even though the gneiss has in many places been formed from original sediments, it clearly has been involved in plastic deformation and has undergone partial mobilization in situ so that the rock is now essentially homogeneous in its physical characteristics. Several quarries to depths of 100 feet or so in granite gneiss in the upper Piedmont show the uniformity and general absence of water-filled fractures in this rock. Granite, granite gneiss, and gabbro should all be suitable for the construction of storage caverns. At depths below 300 feet, open joints or fractures are rare in these rocks. Any fractures that were encountered could be sealed off by grouting. Rock removed in excavating a storage cavern would meet specifications for aggregate for a variety of purposes, including dam and highway construction.

NATURAL GAS PIPELINES



NOTE: Includes service authorized thorough Jan. 1, 1959.
Locations are approximate.

SOUTH CAROLINA
STATE
DEVELOPMENT BOARD

SCALE IN MILES

Area where Cooper marl may be suitable for storage caverns

NATURAL GAS PIPELINE FACILITIES IN SOUTH CAROLINA

Figure 98.

Caverns in Cooper Marl

Over an area of about 1,000 square miles centering on the port of Charleston, the Cooper marl of Eocene and or Oligocene age may be well suited for underground storage caverns (figure 98). This formation is an olive green silty-feeling marl consisting of 25 to 75 percent carbonates, 10 to 45 percent sand, 2 to 5 percent clay, up to 20 percent phosphate, and about 15 to 25 percent water (Malde, 1959, p. 9).

In appearance and physical characteristics the Cooper marl is quite homogeneous. Though very porous and saturated with water, the marl has an extremely low permeability. It can be excavated rapidly and at very low cost. Water for the city of Charleston has for many years been obtained from the Edisto River through a 23-mile long, 7-foot diameter, unlined tunnel in Cooper marl. Tunnel construction costs were a little less than $10 per foot for 18.61 miles constructed in 1936-37 (Gibson, 1942, p. 121). In 1959, a short tunnel was constructed for an over-all cost of about $13.50 per foot. Inspection trips through the several tunnels now in use have shown that sloughing of roof and walls is practically nonexistent though the unsupported tunnel is as much as 70 feet below the ground surface in places.

The Cooper marl is about 150 to 200 feet thick in the Charleston area and is usually overlain by less than 80 feet of younger, unconsolidated sediments. A possible objection to storage caverns in the marl is the difficulty of obtaining depths greater than 200 to 250 feet. The extremely low permeability of this formation suggests, however, that satisfactory storage could be obtained at depths less than those normally required. The possibility of obtaining greater depth by tunneling or sinking shafts in the marl south and east of the city of Charleston should also be considered. The Cooper marl thickens and has a gentle original dip in this direction.

Water-Sand Storage

In the lower Coastal Plain of South Carolina, interbedded sands and clays of the Tuscaloosa and Black Creek formations of Upper Cretaceous age provide an environment potentially suitable for natural gas storage. These units total 500 to 2,000 feet or so in thickness and make up most of the geologic section below depths of about 500 feet. The rocks have been only very gently folded, but closed structures probably exist. Some faulting is known and may have caused traps also. Stratigraphic traps formed by overlap of younger clayey units on older sands may also be expected. Eventually, accumulating geophysical data and subsurface information from drilling will point toward specific areas where water-sand storage of gas may be successful.

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SOUTH DAKOTA

Allen F. Agnew, State Geologist

Introduction

In May, 1960, the natural gas industry had 192 underground storage projects, with 25 new ones in the testing or planning stages (Bizal, 1960). South Dakota is not included among the 22 states where these projects are located.

Most of the storage is in depleted gas and or oil pools, with the remainder in aquifers (water-bearing formations). Storing gas in depleted oil pools seems to have better economic potentialities than storing it in depleted gas pools because of the possibility of secondary recovery of liquid hydrocarbons, which would cancel part if not all of the expense of the storage operation.

Major considerations for a depleted oil or gas pool to be used for underground storage of natural gas are listed by McNutt and Chappelle (1960), as follows:

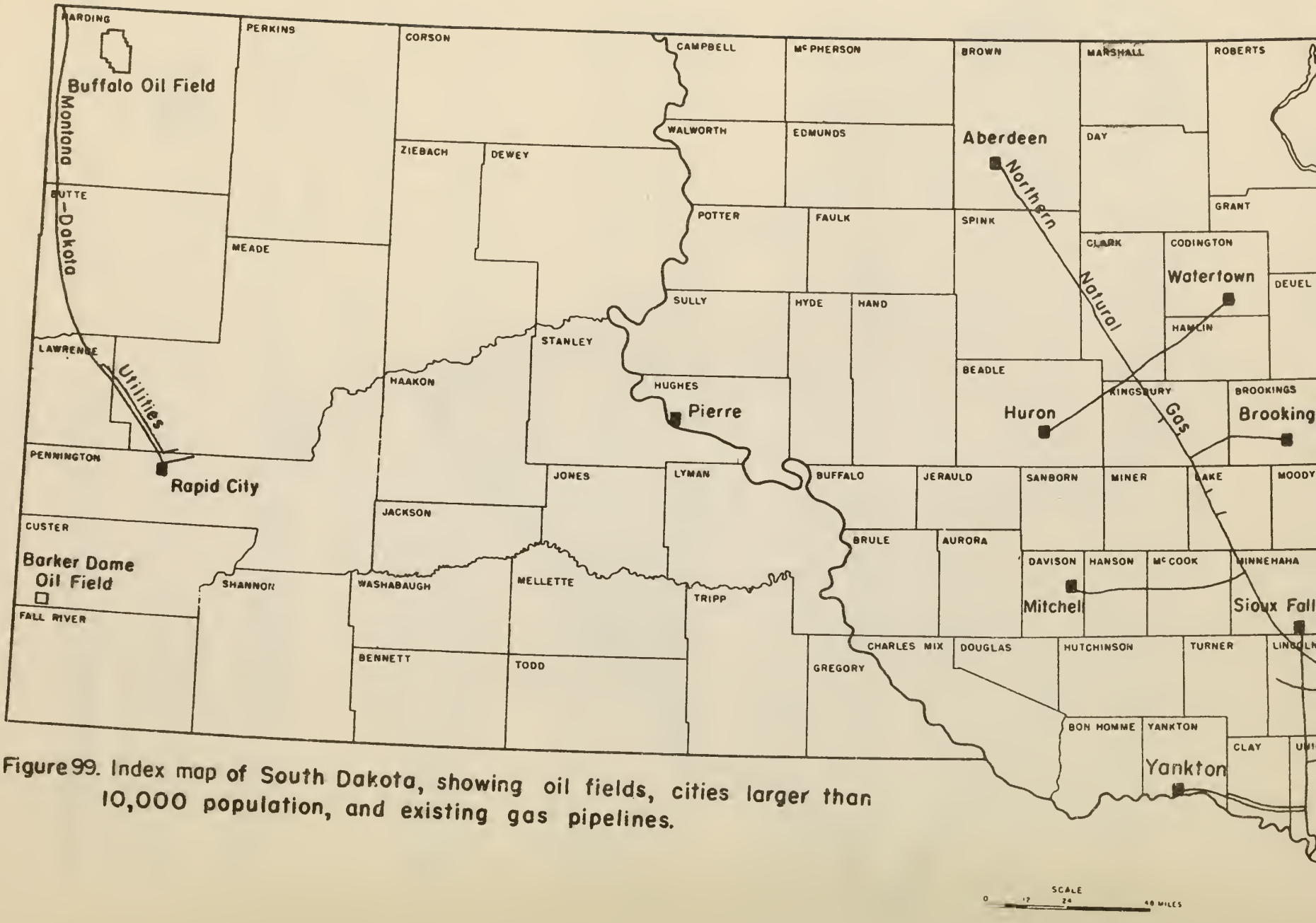

Figure 99. Index map of South Dakota, showing oil fields, cities larger than 10,000 population, and existing gas pipelines.

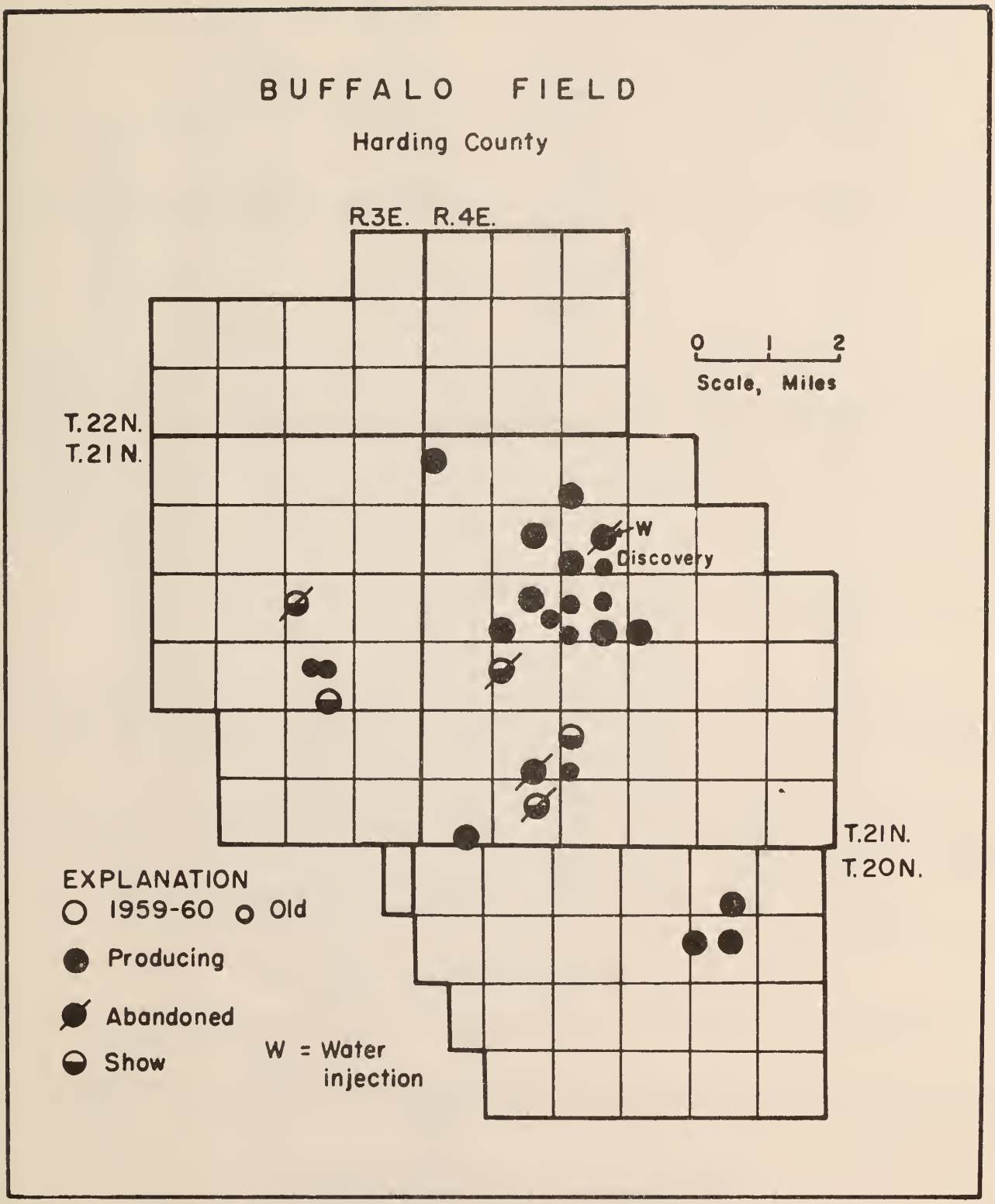

Figure 100. Map of Buffalo Oil Field, Harding County.

1. Geographic location of the depleted pool.
2. Availability of the depleted pool.
3. Number of wells in the depleted pool.
4. Initial capacities of the wells.
5. Cost of acquiring the necessary leases.
6. Cost of reworking the wells to prepare the pool for storage.

Underground storage of natural gas in aquifers is practiced in several states, including the neighboring one, Iowa.

Potentialities of storage of gas under geologic conditions suitable for LPG (liquid petroleum gas) storage, such as in salt cavities and cavities mined in granite, should be investigated.

Gas Production in South Dakota

Buffalo Field

The Buffalo oil field, in Harding County (figure 99), has produced 56,720 Mcf of gas from its discovery in May, 1954, until December 31, 1960. The oil pool is in the Ordovician Red River dolomite at a depth of 8,500 feet; the producing zone is 12-20 feet thick. The gas-oil ratio is low, generally less than 100 Mcf per bbl. and the water-oil ratio ranges from 1:5 to 20:1. Reservoir pressure is variable; initial reservoir pressure was as high as 3,575 psi in one well, but it had declined in this well to about 3,050 psi in November, 1960. The oil lies along minor folds on the northeast-dipping limb of the Cedar Creek Anticline, near its southern end. Porosity and permeability are variable, and the hydrodynamics of the pool are not adequately known as yet. The productive zone is overlain by 40-60 feet and underlain by 300 feet of dolomite of the same formation. On December 31, 1960, nineteen wells were producing (figure 100).

The Buffalo Field is 125 miles north of Rapid City which is the nearest major consuming area. Rapid City has a population of 42,500 (1960).

Barker Dome Field

The Barker Dome Field is in Custer County (figure 99) and has produced only a small amount of oil in its five-year life. The oil has been pumped sporadically from only one well, although several others throughout the past 30 years are said to have produced small amounts of oil for short periods. Gas is present with the oil in one well which has never been completed as a producer.

The oil pool is in one of the "Leo" sands of the Pennsylvanian Minnelusa Formation at a depth of 1,400 feet. The producing zone is about two feet thick and is in a series of dolomite, anhydrite, red shale, and sandstone. The accumulation is related to a small structural dome. Information on porosity, permeability, and reservoir pressure is not available.

The Barker Dome Field is 50 miles southwest of Rapid City, but a longer pipeline would probably be needed in order to skirt the rugged topography of the central part of the Black Hills.

Gas Pipelines and Population Centers in South Dakota

Gas pipelines serve the eastern side of the state as far north as Aberdeen (figure 99) and the western fringe as far south as Rapid City, thus reaching the major population centers in South Dakota.

The eastern line, owned by the Northern Natural Gas Company, obtains its product from Mid-Continent fields. The western, owned by Montana-Dakota Utilities, is fed by production in the Baker area of eastern Montana.

Stratigraphy and Structural Geology of South Dakota With Reference to Underground Gas Storage

The stratigraphic column for South Dakota and information pertinent to underground gas storage are shown in table 33.

Table 33. - Generalized Stratigraphy of South Dakota with Reference to Underground Gas Storage

System	Smaller Stratigraphic Divisions	General Stratigraphic Information	Remarks Pertaining to Gas Storage
Quaternary	Pleistocene and Recent	Unconsolidated surface or near-surface continental deposits of clay, silt, sand, and gravel in valley fills and terraces in all parts of the state; mixed glacial drift east of the Missouri River; thickness as much as 750 feet.	Important fresh-water aquifers abundant; unsuitable for gas storage because of probable lack of impervious seal.
Tertiary	Pliocene, Miocene, Oligocene	Ogallala, "Arikaree", and White River - unconsolidated to semi-consolidated continental deposits of mainly silt and fine sand with some clay, gravel and ash; widespread along the south-central border; thickness as much as 900 feet.	Important fresh-water aquifers; unsuitable for gas storage because of probable lack of impervious seal.
	Paleocene	Tongue River, Cannonball, Ludlow - unconsolidated to consolidated deposits of mainly silt and fine sand with some clay and lignite, and local cemented sandstone lenses; locally in northwestern part of State; thickness as much as 650 feet.	Poor source of fresh water; unsuitable for gas storage because of probable lack of impervious seal.
		Hell Creek - like Paleocene beds above; thickness as much as 600 feet.	Unsuitable for gas storage.
		Fox Hills - marine sand, silty clay, and sandstone; in northwestern third of state; thickness as much as 340 feet.	Fresh-water source; unsuitable for gas storage because of probable lack of impervious seal.

Table 33. - Generalized Stratigraphy of South Dakota with Reference to Underground Gas Storage (Continued)

System	Smaller Stratigraphic Divisions	General Stratigraphic Information	Remarks Pertaining to Gas Storage
Cretaceous	Upper Cretaceous	Pierre - marine partly bentonitic and silty shale in most of state, 1000-1200 feet thick. At base, Gammon sandy shale and Groat sandstone around northern part of Black Hills and to north, as much as 800 feet thick (Robinson, Mapel, and Cobban, 1959).	Possibility of mined cavities in shale small because of great engineering problems. Eagle sand is gas-producing along domes in Harding County, and might be investigated for gas storage there.
		Niobrara - marine chalk, marl, and calcareous shale in all but northwestern part of state and along the Sioux Ridge in southeastern part; thickness 150-200 feet.	Local fresh-water source in southeastern part of state south of Sioux Ridge. Possibilities for gas storage locally, where overlain by impervious seal.
		Carlile - marine shale; local sandstone (Turner? or Codell?), 200-250 feet thick in southern part of state; thickness about 550 feet.	Sand is fresh-water source, perhaps connected with overlying Niobrara. Possibilities for gas storage locally.
	Cretaceous ?	Greenhorn - marine limestone and calcareous shale. Belle Fourche - marine shale and bentonite. Mowry - marine siliceous shale and sandstone lenses. Total thickness as much as 900 feet.	Thin lenticular sands in southern Black Hills (Wall Creek?) are poor gas sources. Unfavorable for gas storage.
		"Newcastle" - lenticular marine sandstone in several benches, each as much as 40 feet thick; in central part of state combines with underlying Fall River into at deltaic sand as much as 400 feet thick.	Local source of fresh water and gas around Black Hills. Source of brackish water and gas in central part of state. Possibilities for gas storage in central area.

Table 33. - Generalized Stratigraphy of South Dakota with Reference to Underground Gas Storage (Continued)

System	Smaller Stratigraphic Divisions	General Stratigraphic Information	Remarks Pertaining to Gas Storage
	Lower	Skull Creek - marine shale; thickness 250 feet; absent in eastern half of state.	Unfavorable for gas storage
		Fall River-Lakota - marine and continental sandstone, siltstone, shale, and lignite (Waage, 1959); thickness 300-335 feet.	Source of fresh and brackish water throughout state. Possibilities for gas storage.
Jurassic		Morrison-Sundance - marine and continental shale and sandstone; thickness as much as 400 feet. "Sundance" in north-central and northeastern parts of state is perhaps Lakota and Sundance sands combined.	Locally fresh and brackish water. Generally unfavorable for gas storage because of lenticularity. "Sundance" of northeastern part of state good source of fresh to brackish water, under considerable artesian pressure.
		Gypsum Springs - local marine sandstone as much as 50 feet thick in Black Hills area; changes toward the north into Piper limestone and calcareous sandstone and shale, as much as 200 feet thick (Peterson, 1957).	Unfavorable for gas storage.
Permian-Triassic	Redbeds	Spearfish - red shale and gypsum. Minnekahta - pink anhydritic limestone. Opeche - red shale and gypsum. All in Black Hills area; about 500 feet thick. Spearfish becomes anhydritic in central part of state, and in northwest. In Harding and Butte counties the Spearfish is overlain by as much as 300 feet of Pine Salt, and that by 100 feet of Saude anhydrite and shale (Ziegler, 1956).	Possibility of leached cavities in Pine Salt for gas storage, in Harding and Butte counties.

Table 33. - Generalized Stratigraphy of South Dakota with Reference to Underground Gas Storage (Continued).

System	Smaller Stratigraphic Divisions	General Stratigraphic Information	Remarks Pertaining to Gas Storage
Permian-Triassic	Upper Minnelusa	Marine and brackish anhydrite, dolomite, limestone, and shale; converse sandstones in northern Black Hills; thickness of upper Minnelusa about 450 feet.	Possibilities of gas storage locally in northern Black Hills in Converse sandstones.
Pennsylvanian	Lower Minnelusa	Marine and brackish limestone, dolomite, anhydrite, red and black shale, and lenticular sandstones (Leo in Black Hills area); thickness 200-800 feet, greatest in southwestern part of Black Hills. "Tyler" sandstone up to 350 feet thick in central South Dakota.	Unfavorable in Leo sandstones because of lenticularity. Possibilities of gas storage locally in "Tyler" sandstone in central part of state, which is potentially oil-bearing (Foster, 1960).
Mississippian		Madison - marine limestone and dolomite, with some anhydrite, in northwestern half of state; thickness as much as 700 feet.	Probably favorable because of great artesian pressure; it is a good source of fresh to brackish water.
		Englewood - marine limestone, about 60 feet thick in Black Hills area.	Unfavorable for gas storage.
Devonian		Three Forks - marine shale and shaly limestone; thickness as much as 40 feet; in northwestern corner of state. Birdbear, Duperow, Souris River - marine limestone and dolomite (Sandberg, Hammond, 1958); thickness as much as 325 feet; in northwestern quarter of state.	Unfavorable for gas storage.

Table 33. - Generalized Stratigraphy of South Dakota with Reference to Underground Storage (Concluded)

System	Smaller Stratigraphic Divisions	General Stratigraphic Information	Remarks Pertaining to Gas Storage
Silurian		Interlake - marine limestone, dolomite, with local red shale at unconformities (Ashern); thickness as much as 375 feet; in northwestern part of state.	Unfavorable because of lack of adequate seal.
Ordovician	Upper Ordovician	Stony Mt. - marine limestone and calcareous shale, in northwestern part of state; thickness as much as 165 feet.	Unfavorable because of lack of adequate seal.
		Red River - marine dolomite and limestone with three zones of water and oil in Harding County but with low gas pressure; as much as 590 feet thick; in western two-thirds of state. (Viola limestone and dolomite in southeastern corner of state).	Possibly favorable for gas storage in Buffalo Oil Field in northwestern corner of state. Source of fresh and brackish water in northwestern and central parts of state.
	Middle? and Upper Ordovician	Winnipeg - marine shale and siltstone, as much as 350 feet thick. Marine sandstone below, as much as 140 feet thick; in most of state; (Simpson shale, siltstone and sandstone in southeastern corner of state).	Shale unfavorable. Sandstone flows fresh and brackish water from 8500 feet in Harding County: possibly favorable for gas storage. Simpson sandstone has oil shows in southeastern corner of state.
Ordovician? - Cambrian	Lower Ordovician? and Upper Cambrian	"Deadwood" - marine sandstone, shale, dolomite; as much as 565 feet thick; in most of state.	Probably unfavorable because of irregular permeability.
Pre-cambrian		Granite, quartzite, metamorphic rocks; granite underlies the other lithologies, and is overlain by several thousand feet of Sioux quartzite in southeastern quarter of state.	Possibility of mined cavities in granite where not too fractured, where overlain with impermeable seal, and where not too deep..

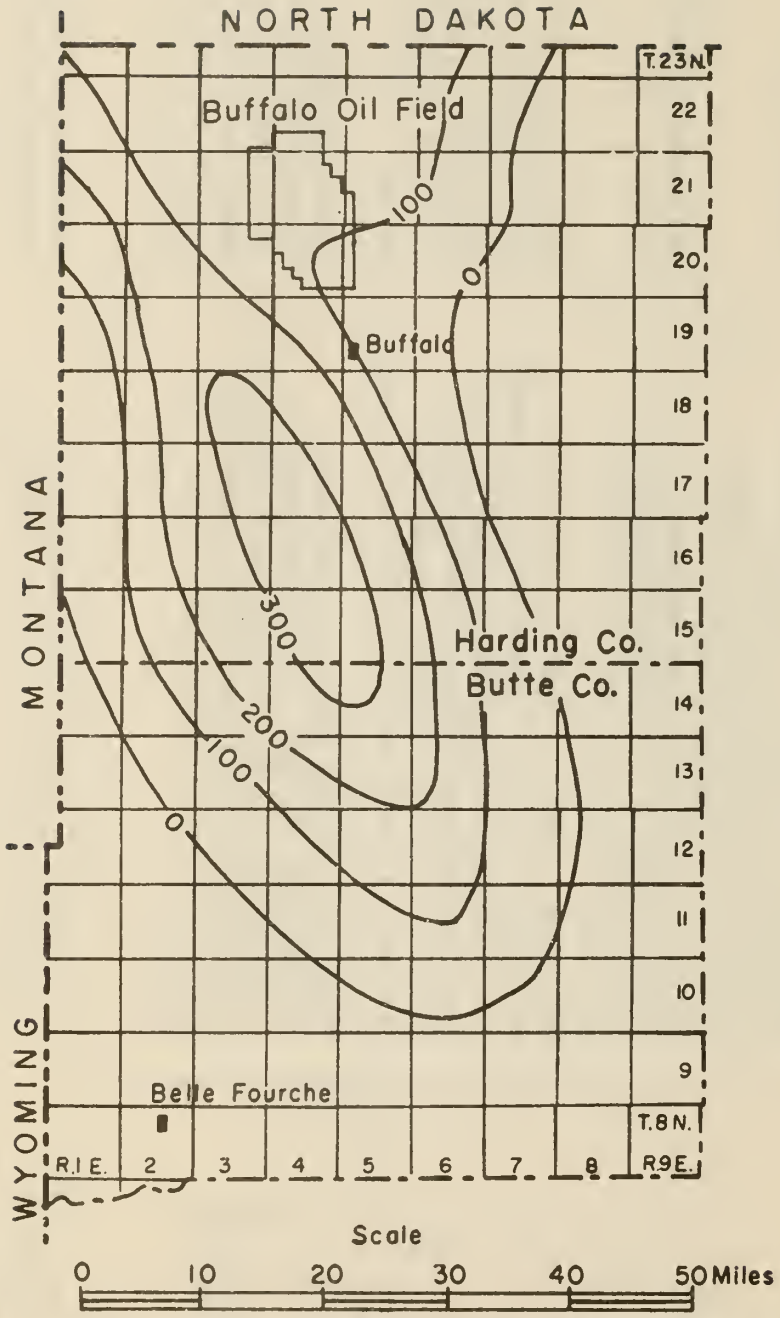

Figure 101. Map of Harding and Butte Counties, Showing distribution of Pine Salt. (Zieglar, 1956)

The stratigraphic units that possibly could serve as underground gas storage reservoirs in the western part of the state include in descending order parts of the Cretaceous Pierre shale, the "Newcastle" sandstone, the Fall River-Lakota sandstone, the Jurassic (?) Pine Salt (in Harding County), the Permian Converse sandstones, and the Ordovician Winnipeg sandstone.

In the southeastern part of South Dakota, possible underground gas storage reservoirs include the Cretaceous Niobrara chalk and Codell sandstone, the "Dakota" sandstone sequence, and the Ordovician "Simpson" or "St. Peter" sandstone (in Union County).

In the northeastern part of the state, possible reservoirs for underground gas storage include the "Dakota" sandstone sequence.

The possibility of gas storage in mined cavities in the Precambrian Sioux Quartzite or older granite in eastern South Dakota is difficult to evaluate because of the presence of fractures and because of the lack of detailed information.

Permeability traps should be expected in the eastern half of South Dakota where the various rock units were deposited from shoaling seas against the Continental Shield. In addition, overlaps and other unconformable situations have given rise to conditions that favor entrapment of fluids in this part of the state.

Permeability traps caused by facies changes are known in the "Newcastle" and Fall River-Lakota sandstones in the Black Hills area and in the Converse sandstones in the northern part of that area.

The general structural elements of South Dakota include the Black Hills Uplift, the Sioux Arch, and the Williston Basin (Agnew, Gries, 1960).

Small anticlines and domes are present in the rocks immediately surrounding the Black Hills and along the Cedar Creek Anticline in the northwestern corner of the state (in Harding County). It is expected that similar structures will be found in the rest of the western half of the state.

Possible Areas for Underground Gas Storage in South Dakota

In many parts of South Dakota, it appears that geologic conditions are favorable for storage of natural gas in porous rocks, as mentioned in the preceding section. In particular, around the Black Hills the "Newcastle", the Fall River-Lakota, and the Converse sandstones might profitably be prospected for small anticlinal traps.

In Harding and Butte Counties, the possibility of dissolved cavities in the Pine Salt should be investigated. This salt is relatively localized (figure 101) and reaches a maximum thickness of 300 feet (Zeigler, 1956). Storage of LPG in a similar salt zone but 3,000 feet deeper has been under way for six months in the deeper part of the Williston Basin, in North Dakota.

In northeastern South Dakota, mined cavities might be developed economically in granite.

In the southeastern part of the state, the possibility of permeability or unconformity traps in the Niobrara chalk and "Codell" sandstone might bear investigation, both where they are overlain by shale, and by glacial drift.

Regulations Affecting Underground Gas Storage

South Dakota currently has no laws or regulations pertaining to the storage of hydrocarbons underground. This material is included, however, in the revision of the Oil and Gas Law proposed by the State Legislative Research Council.

In other states, regulations governing the underground storage of natural gas or LPG are administered by the agency that regulates the oil and gas producing industry. Thus it is recommended that the State of South Dakota promulgate regulations to control the underground storage of liquid and or gaseous hydrocarbons, and that the State Oil and Gas Board administer these regulations.

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TEXAS

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General Remarks

To date, the State of Texas has seven underground storage reservoirs for natural gas. Six of these reservoirs are owned and operated by Lone Star Gas Company and one, the Caddo Storage Reservoir in the Janellan Field, is owned and operated by Pioneer Natural Gas Company.

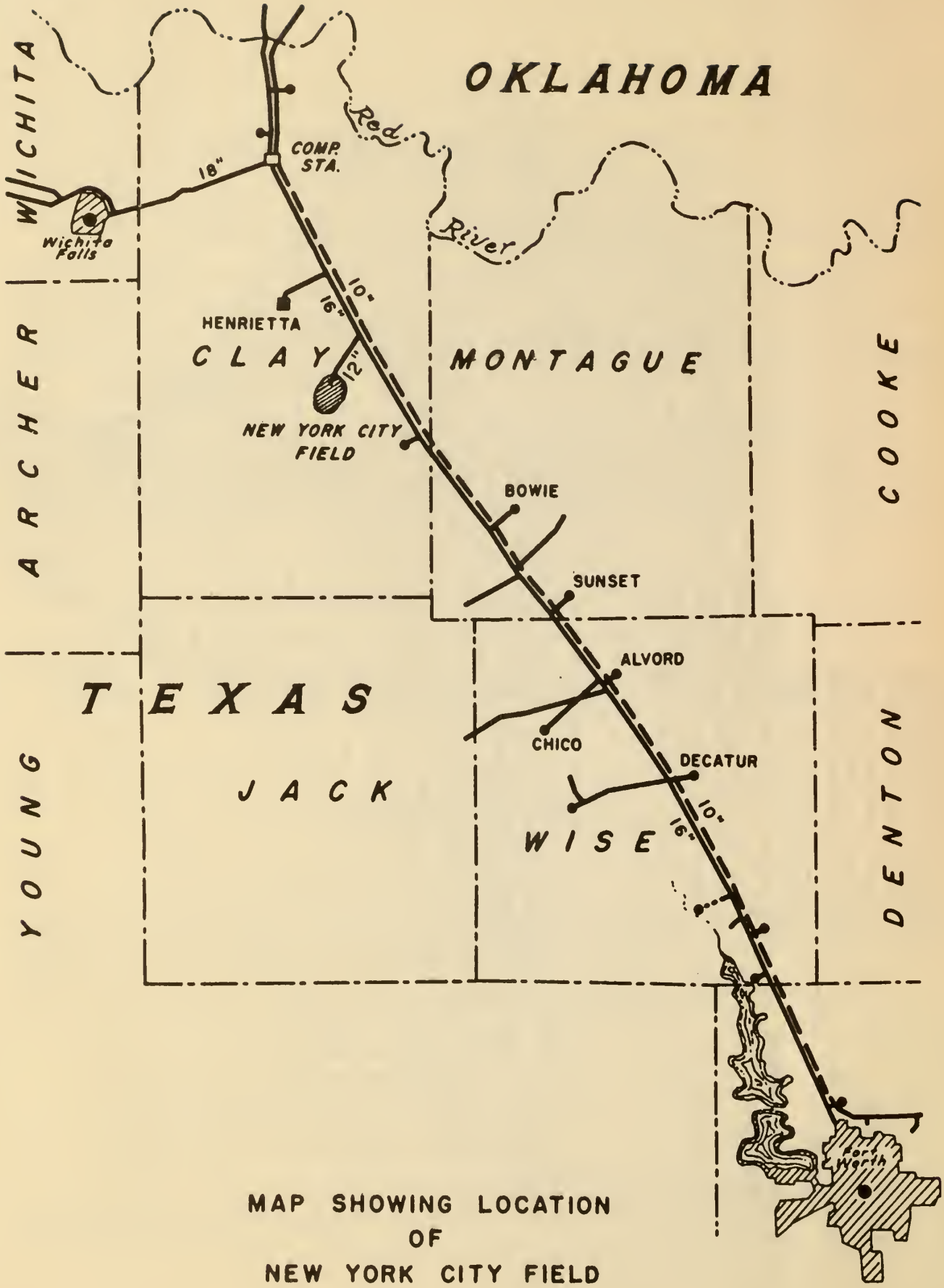
We are presently storing gas in the following fields in Texas (figure 102):

1. New York City (Mississippian) - Clay County, Texas
2. Ambassador (Mississippian) - Clay County, Texas
3. Leeray (Moran) - Stephens County, Texas
4. View (Flippen) - Taylor County, Texas
5. Tri-Cities (Bacon) - Henderson County, Texas
6. Tri-Cities (Rodessa) - Henderson County, Texas
7. Janellan (Caddo) - Brown County, Texas.

Gas storage operations in these reservoirs were approved by the Railroad Commission of Texas. Each reservoir was designed to conserve natural gas by the use of controlled production the year around and to improve gas service to the public.

MAP OF
TEXAS
GENERAL LAND OFFICE
-AUSTIN-
BILL ALLCORN
COMMISSIONER
Storage Reservoirs
NEW MEXICO
OKLAHOMA
LOUISIANA
MEXICO
GULF OF MEXICO
RED RIVER
RIO GRANDE
SABINE RIVER
AMBASSADOR
NEW YORK CITY
LEERAY
VIEW
TRI-CITIES
JANELLAN

Figure 102



MAP SHOWING LOCATION
OF
NEW YORK CITY FIELD

Figure 103.

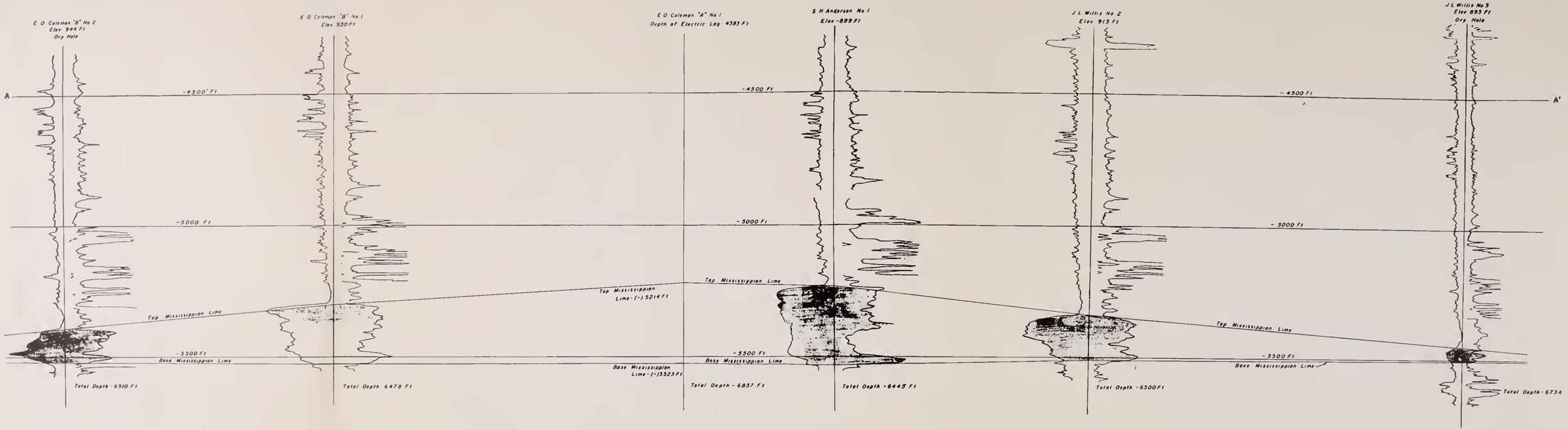


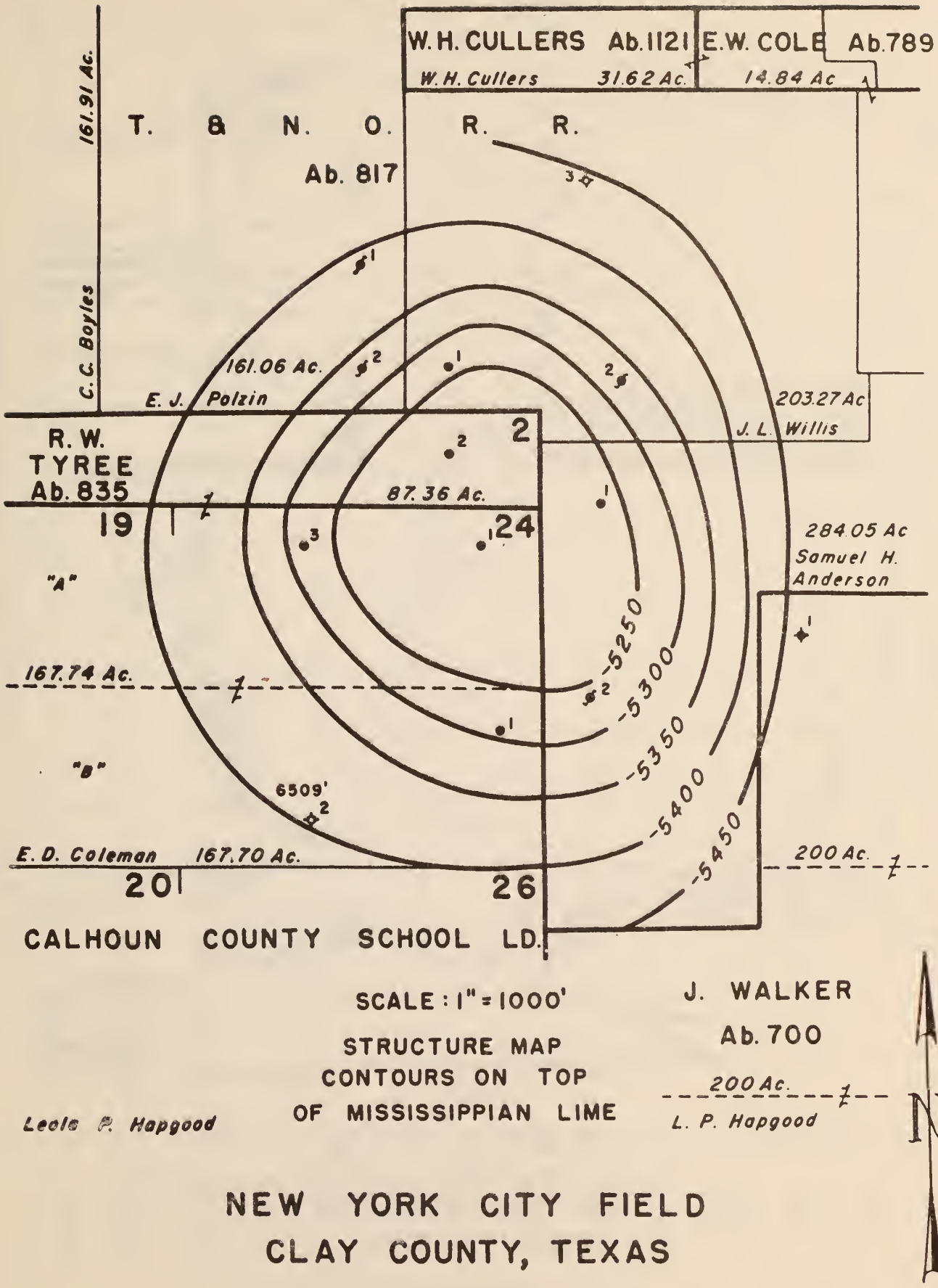
Figure 104

NEW YORK CITY FIELD

CLAY COUNTY TEXAS

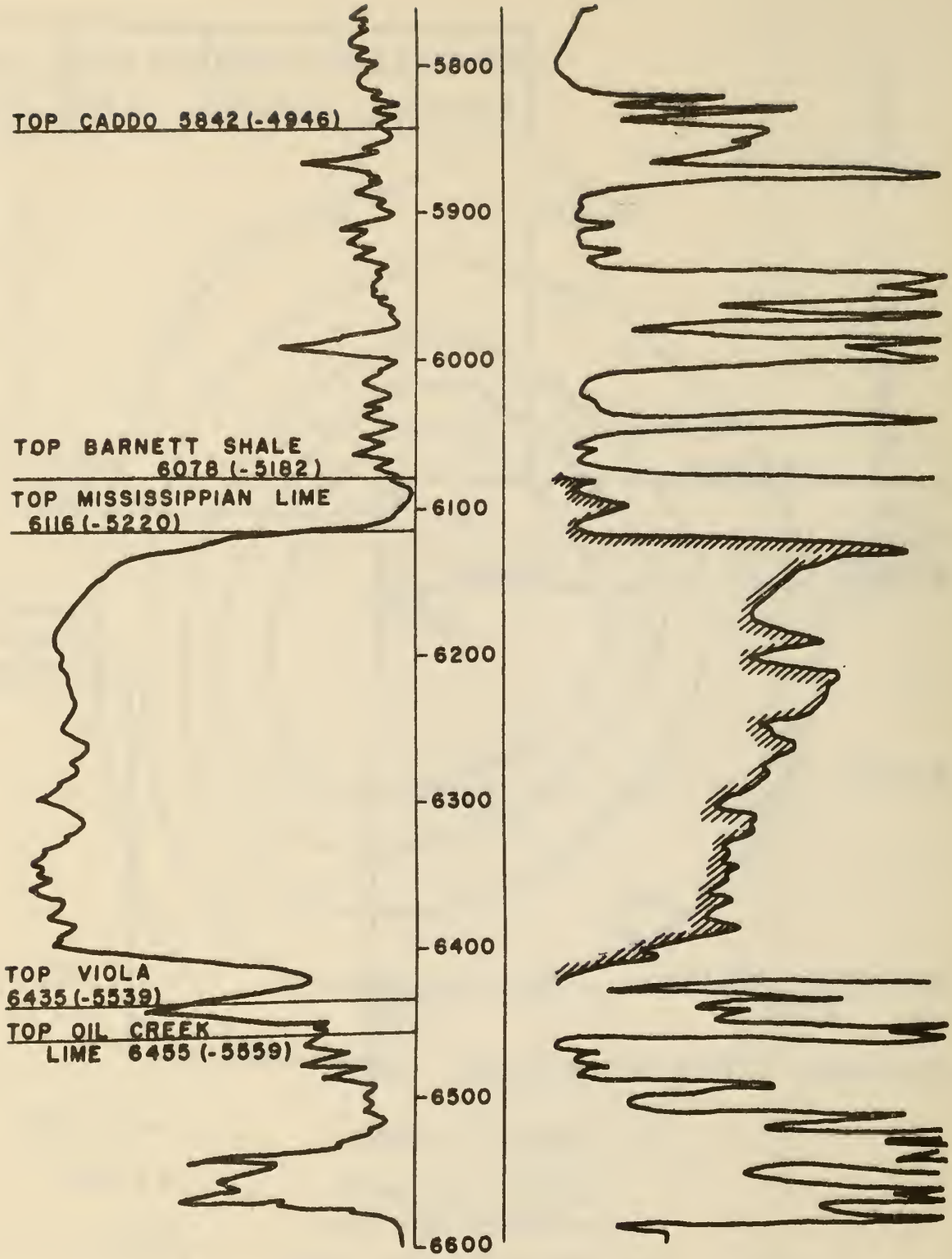
CROSS SECTION A-A'

Scale: 1" = 100'



NEW YORK CITY FIELD
CLAY COUNTY, TEXAS

Figure 105.



ELECTRIC LOG OF
ED. COLEMAN A-I WELL
NEW YORK CITY FIELD
CLAY CO., TEXAS

Figure 106.

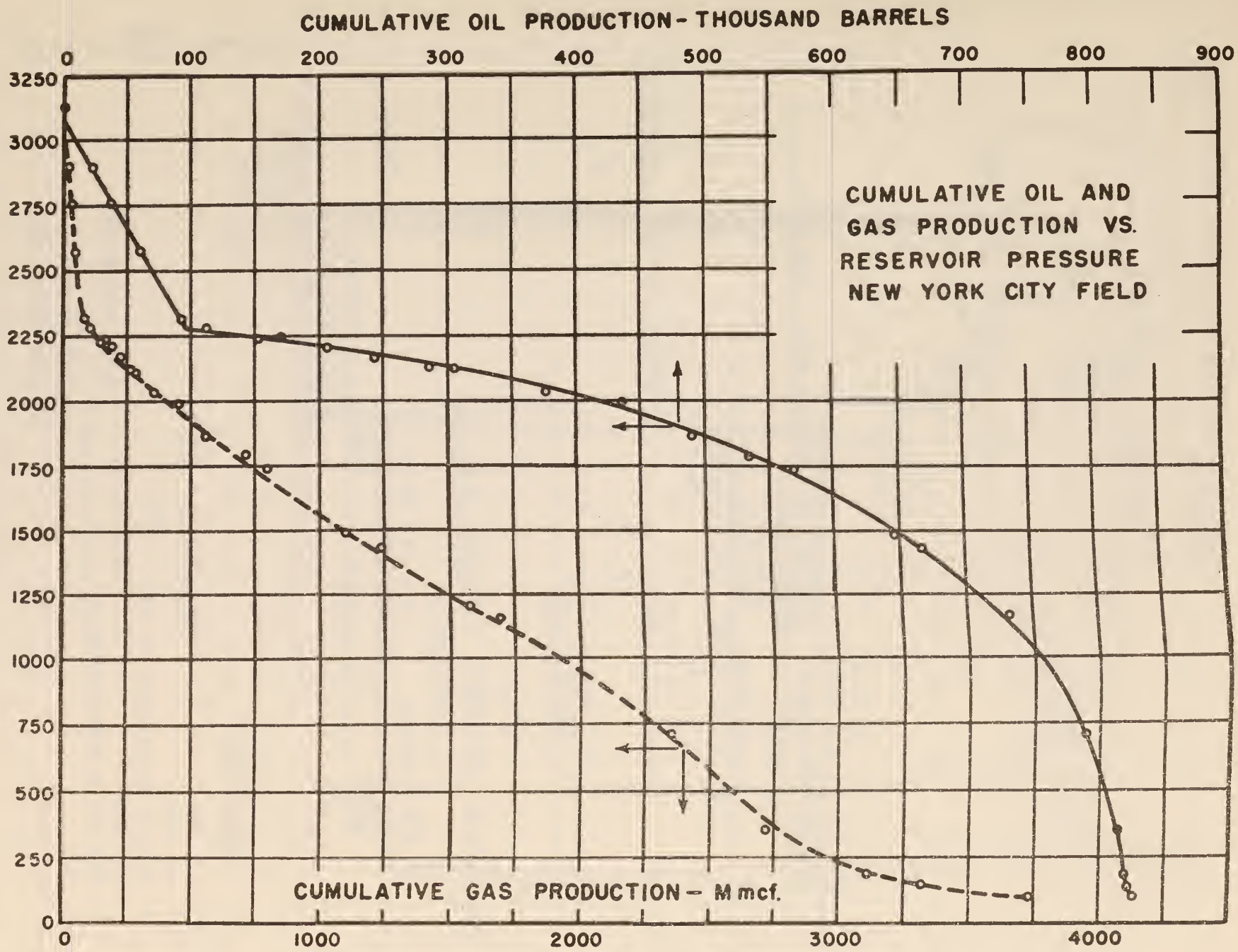
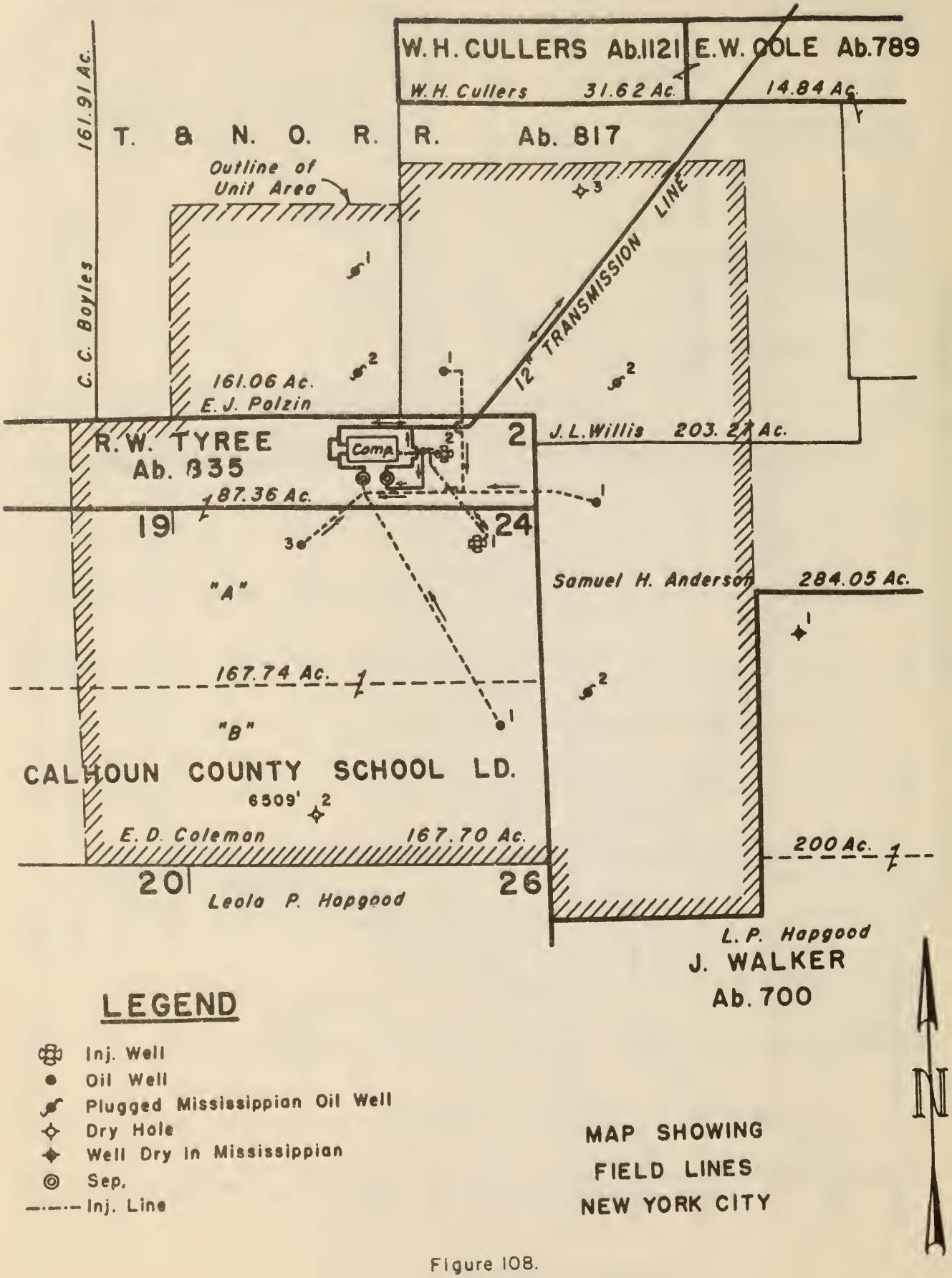
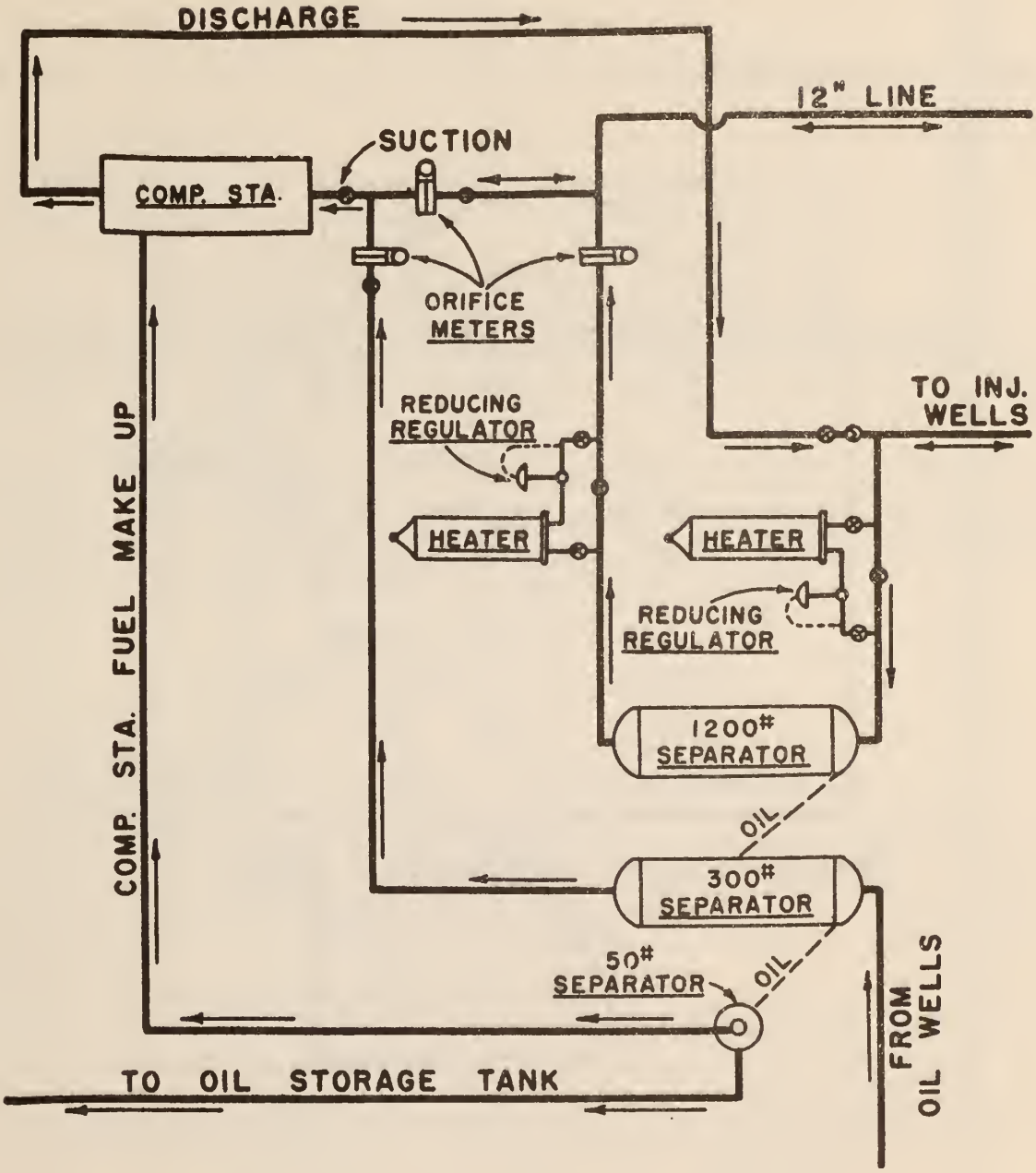

CUMULATIVE OIL PRODUCTION - THOUSAND BARRELS
0
100
200
300
400
500
600
700
800
900
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
RESERVOIR PRESSURE - Psig.
CUMULATIVE OIL AND
GAS PRODUCTION VS.
RESERVOIR PRESSURE
NEW YORK CITY FIELD
CUMULATIVE GAS PRODUCTION - M mcf.
0
1000
2000
3000
4000

Figure 107.



MAP SHOWING
FIELD LINES
NEW YORK CITY

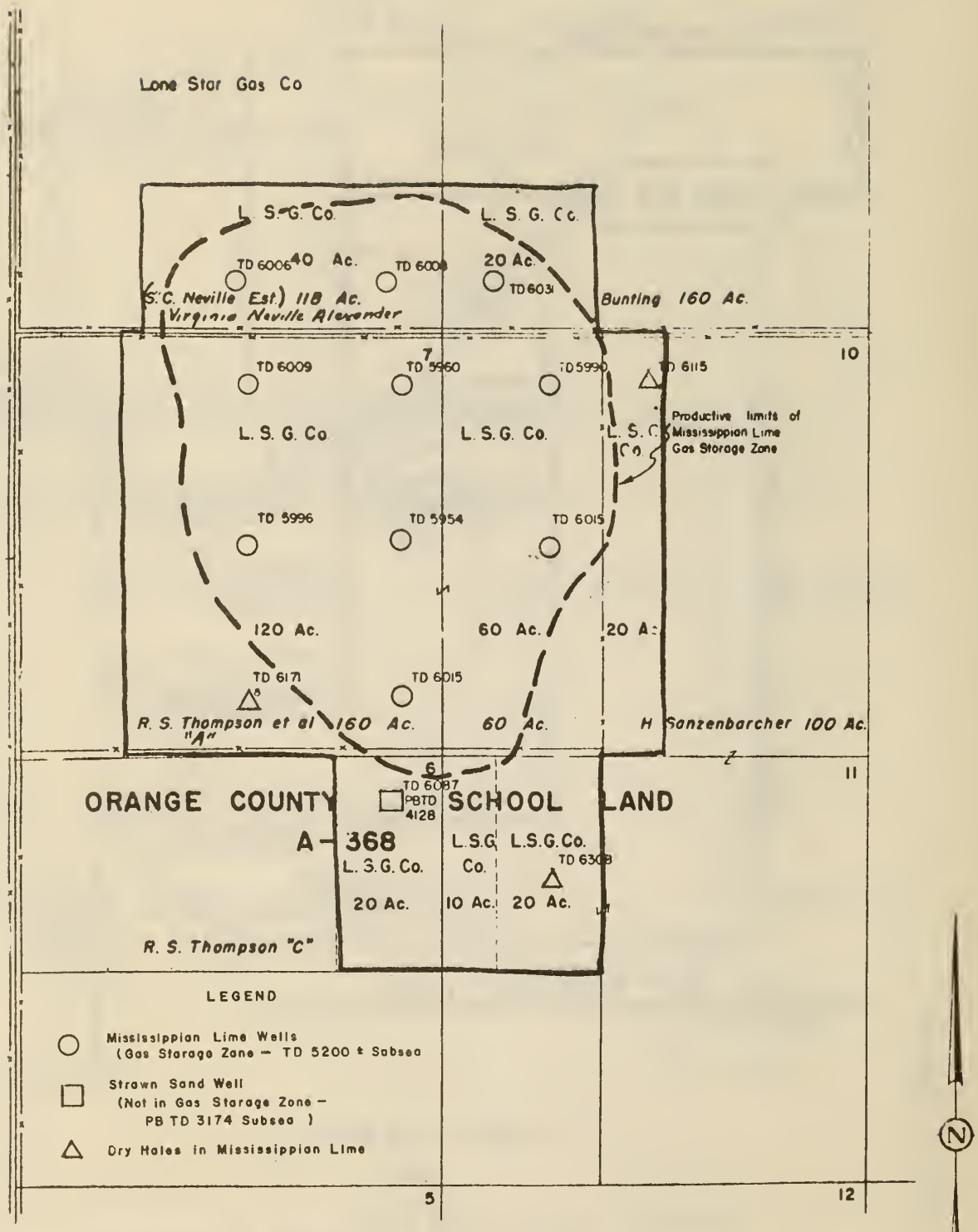
Figure 108.



FLOW DIAGRAM OF STATION

New York City Field

Figure 109.



AMBASSADOR FIELD

GAS STORAGE UNIT (310 Acres)

CLAY COUNTY, TEXAS

Figure 110

Reservoir Conditions

The primary considerations for an oil or gas field to be used for underground storage of natural gas are:

1. Geographical location
2. Field availability
3. Number of wells in field
4. Initial well capacities
5. Cost of acquiring necessary leases
6. Cost of reworking wells to prepare field for storage.

Reservoirs which formerly produced oil or gas are used for natural gas storage in Texas. No water sands or salt domes have yet been used. These reservoirs are naturally gas-tight. Of the seven reservoirs in use to date in Texas, three are depleted oil reservoirs, three are depleted gas reservoirs, and one is a depleted oil and gas reservoir.

Storing gas in depleted oil reservoirs seems to be far superior to storing gas in depleted gas reservoirs because of the possibility of secondary recovery of liquid hydrocarbons which could possibly defray in part, if not wholly, the expense of the storage operation. Secondary recovery is brought about by cycling during off-storage periods and by high gas withdrawal rates from edge wells during peak demand periods. With the exception of the Caddo storage reservoir in the Janellan Field, the ultimate liquid recovery from all underground storage projects in Texas is expected to exceed 5,000,000 barrels.

Gas Storage Projects in Texas

New York City Field (a depleted oil reservoir)

Operator - Lone Star Gas Company
Location - Clay County, Texas
Discovered - April, 1941
Production and Field Information - Production is from ten wells drilled in the field to the producing 6,100 feet closed limestone reservoir. The porosity pinches out completely in all directions. There is no indication of any water drive in an area of 400 acres covered by the reservoir. The original reservoir pressure was 3,120 psi, and final reservoir pressure was 80 psi. The field produced 824,000 barrels of oil and 4,500 million cubic feet of gas. In the past five years, the New York City Storage Project has recovered over 406,000 barrels of crude oil from the large-volume oil wells in the field.
Reservoir Information - Each well in the reservoir is equipped to inject and withdraw stored gas. Lone Star Gas Company estimates the capacity of the reservoir at 3,000 psi to be six billion cubic feet of gas.
Compressor Facilities - The compressor is sufficient to store 20 million cubic feet of gas per day and withdraw 60 million cubic feet per day at a maximum reservoir pressure of 3,000 psi. The compressor station consists of three Cooper-Bessemer (G. M. V.) type gas engines with a rating of 880 horsepower each.

Ambassador Field (a depleted oil reservoir)

Operator - Lone Star Gas Company
Location - Clay County, Texas (six miles west of New York Field)
Discovered - December, 1950
Production and Field Information - Production was from the Chappel (Mississippian) lime at approximately 6,000 feet. The reservoir underlies an area of approximately 175 acres and is a closed reservoir. The field produced 415,000 barrels of crude oil and 1,110,000 Mcf of gas by primary production methods from ten producing wells. The initial reservoir pressure was 2,879 psi. The ultimate recovery anticipated with gas storage providing the necessary energy is approximately 472,907 barrels.
Reservoir Information - The final storage capacity of this reservoir is 1,566,525 Mcf of gas which is available during peak demand periods. The working pressure is 2,800 psi. Oil is produced when the reservoir is at capacity during low demand months by gas cycling operations.

Leeray Field (a depleted dry gas reservoir)

Operator - Lone Star Gas Company
Location - Stephens County, Texas
Discovered - March 24, 1929
Production and Field Information - Production is from the Strawn sand at approximately 2,000 feet from seven producing wells. Eleven wells have been completed in the closed reservoir. The field has produced 5,811,703 Mcf of gas from 1,600 acres covered by the reservoir. The initial average shut-in pressure was 890 psig with no indication of water drive.
Reservoir Information - This Strawn sand reservoir has a capacity of 7,080,000 Mcf, of which 2,080,000 Mcf is cushion below 250 psi.
Compressor Facilities - The Leeray Storage Reservoir has a minimum withdrawal pressure of 250 psi. The production pressure is in the range of 250 psi to 700 psi. A 600 H. P. compressor station discharges a maximum pressure to storage of 800 psi.

View Field (a depleted oil and gas reservoir)

Operator - Lone Star Gas Company
Location - Taylor County, Texas
Discovered - Early 1930
Production and Field Information - Production is from the Flippen Limestone Formation topped at an average depth of 2,350 feet. There were 12 oil well completions and seven gas well completions in the closed reservoir. In 1942, the total production per day from the 12 oil wells was 16 barrels. The average shut-in pressure was approximately 250 psi. The estimated cumulative production of oil is 440 million barrels.
Reservoir Information - There are four injection wells in this field used to inject approximately six million cubic feet of gas per day with well-head injection pressures of 900 psi or under. The capacity of the reservoir is approximately 2,000,000 Mcf.
Compressor Facilities - The maximum injection pressure expended by the compressor is 900 psi. The withdrawal pressures depend upon the volume of gas in storage and range from 350 to 750 psi.

Tri-Cities Field (2 storage reservoirs)

Operator - Lone Star Gas Company
Location - Henderson County, Texas
Discovered - 1941
Production and Field Information -

A. The Bacon Lime Reservoir (a depleted gas-distillate reservoir)
Production is found at approximately 7,600 feet. The initial distillate content was approximately 80 barrels per MMcf. The reservoir pressure was initially 3,200 psi, but after production of 22 million Mcf of gas and 1,051,000 barrels of condensate the pressure was reduced to 375 psi. This closed reservoir pinches out on the south, west and north; and a major fault is located to the east. This reservoir has approximately 4,000 acres of productive acreage with an average net thickness of eight feet. The average porosity is estimated to be 10%.

B. The Rodessa Lime Reservoir (a depleted oil reservoir)
Production of this reservoir is found at approximately 7,700 feet. The reservoir pressure was initially 3,200 psi, but after production of 8,320,000 Mcf of gas and 1,978,600 barrels of oil the pressure was reduced to 275 psi. This reservoir is closed by the water level which occurs at approximately 7,340 feet sub-sea on the south, west and north, and closure on the east by a major fault. This reservoir has approximately 1,400 acres of productive area with an average net thickness of eleven feet. The average porosity is estimated to be 15%.

Reservoir Information - The Rodessa Reservoir will hold eight million Mcf of gas at 3,000 psi, and the Bacon Reservoir will hold 20 million Mcf at 3,000 psi. The differential between reservoir and injection pressure at the well-head is 400 psi. Maximum injection working pressure is, therefore, 3,400 psi. Rodessa and Bacon storage wells are produced at a maximum working pressure of 1,200 and 2,000 psi, respectively. Between July and October of each year, these reservoirs are filled to capacity. During this period of low demands, the stored gas is cycled in the reservoirs

LEERAY FIELD

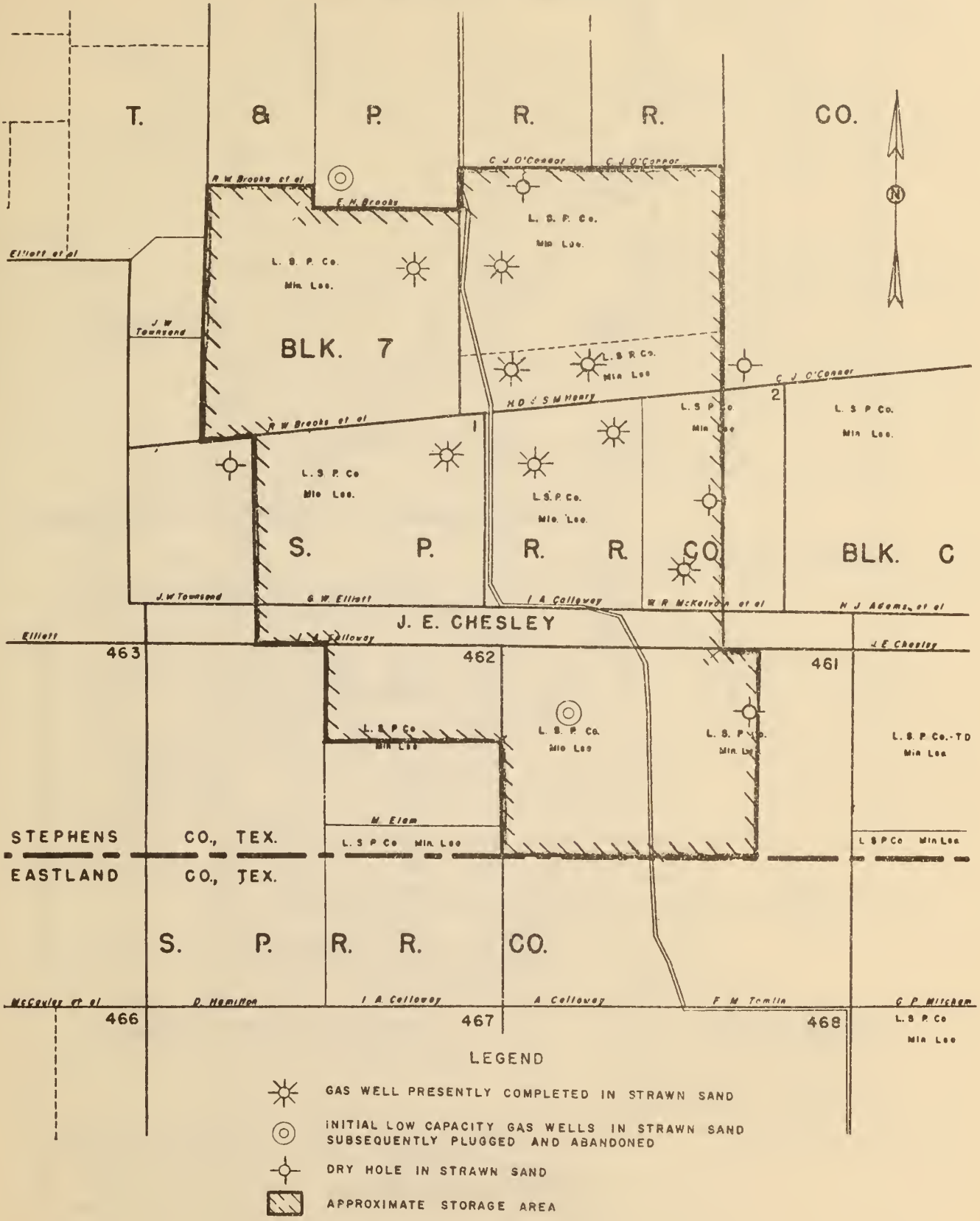
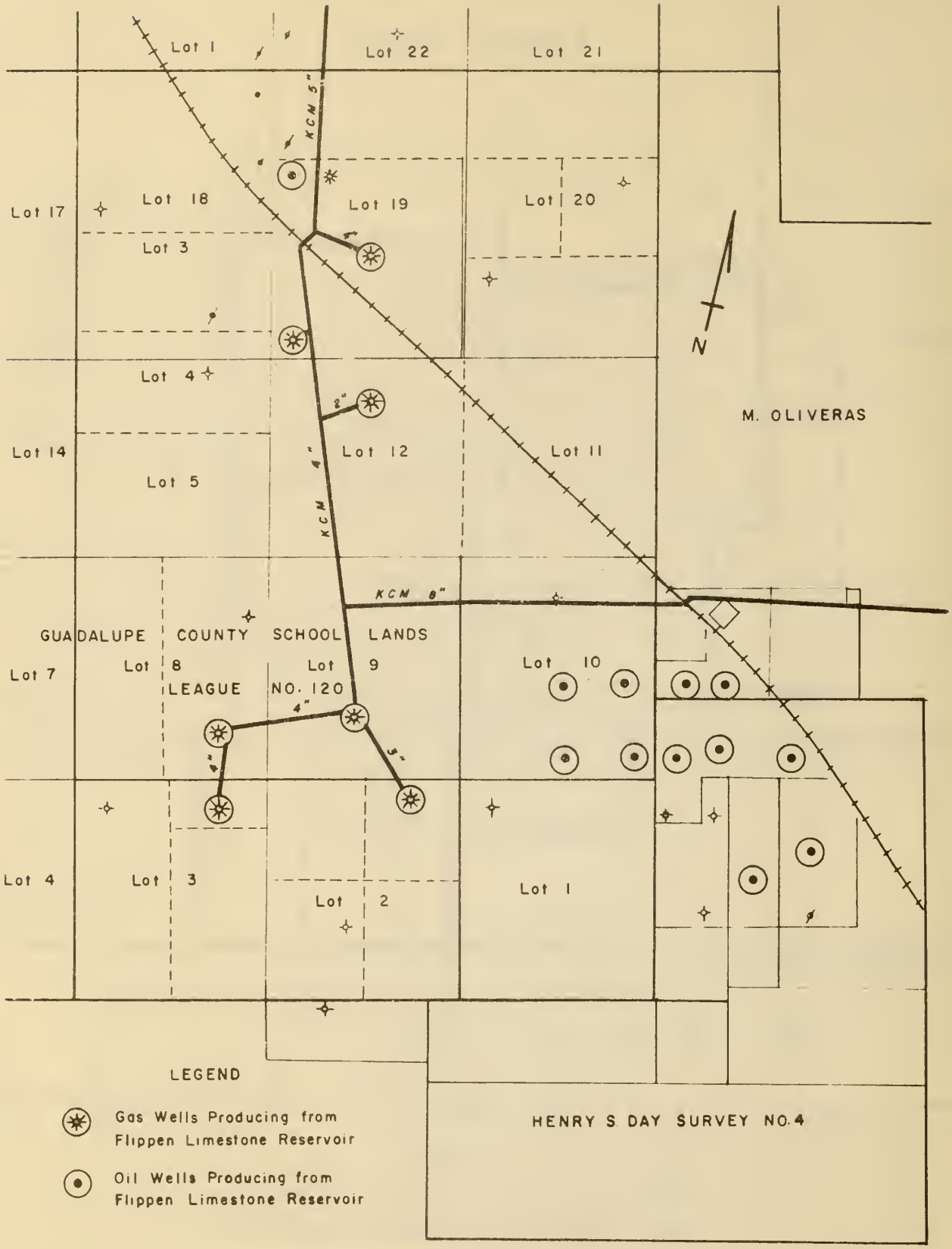
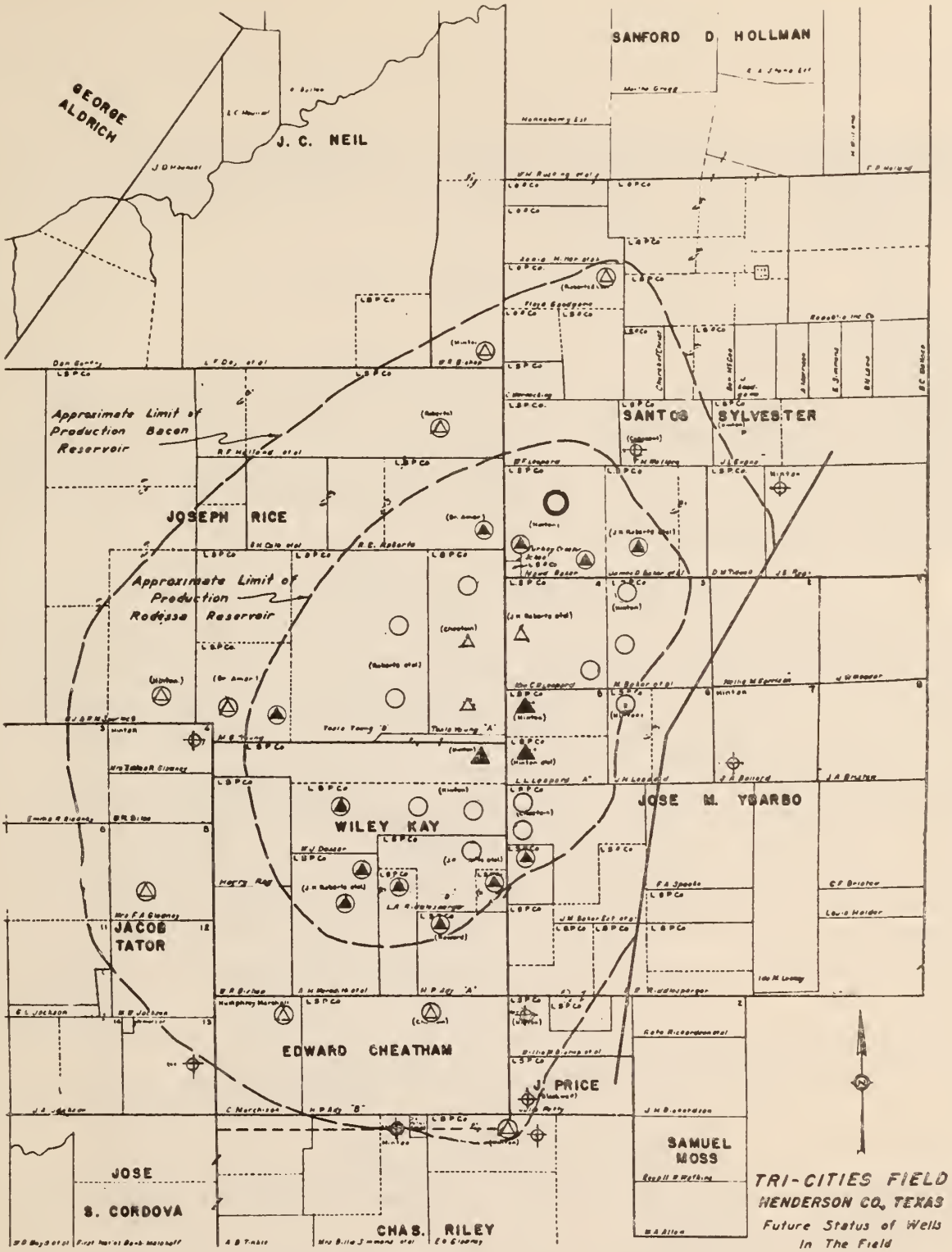


Figure III.



VIEW FIELD
TAYLOR COUNTY, TEXAS

Figure 112.



LEGEND

- ▲ Rodesso Injection Well
- △ Bocon Injection Well
- Rodessa Withdrowol Well
- Bacon Withdrowol Well
- ○ Inactive – Possible Injection Well
- Plugged Well
- O Duol Completed Rodesso ond Travis Peok Withdrawal Well

Figure 113

by using the compressor facilities which would otherwise be idle during this period. This operation provides for the recovery of salable products which, in turn, defers the cost of the storage operation. The storage reservoirs are also enlarged by the removal of the oil and condensate.

Compressor Facilities - The injection compressors consist of three 1,800 H. P. units by the installation of super-charging facilities.

The Janellan Field (a depleted gas reservoir)

Operator - Pioneer Natural Gas Company
Location - Brown County, Texas
Discovered - 1918
Production and Field Information - Continual production since 1919 is from 18 wells in the closed Caddo Reservoir located at an average depth of from 1,050 feet to 1,200 feet and covers an area of approximately 4,000 surface acres with an average thickness of 20 feet to 25 feet. Cumulative production to March 31, 1960, totals 18,933,874 Mcf. Remaining recoverable reserves are estimated at 2,149,235 Mcf to 50 psig abandonment pressure. Current wellhead pressure is 85 psig.
Reservoir Information - At a reservoir pressure of 200 psi, it is estimated that 5,000,000 Mcf could be stored in this reservoir.
Compressor Facilities - No information available.

Regulations Affecting Storage Projects

The Railroad Commission of Texas administers all regulations affecting the storage of natural gas underground. Customarily, the applicant who wishes to participate in the storage of natural gas submits for approval to the Railroad Commission reasons for storing natural gas. The applicant also submits proposed rules for the storage operation. The rules proposed for the New York City field storage project are representative of other fields in Texas and are summarized as follows:

Rule 1 would classify the New York City Mississippian lime field as a gas storage field, and all wells therein would be classified as gas storage wells. Monthly reports must be submitted to the Commission on the applicable forms showing volumes of gas injected, gas produced, and quantities of liquid hydrocarbons proposed.

Rule 2 would provide sufficient flexibility to permit development of adequate gas storage and withdrawal capacity; no spacing limitation shall apply to gas storage wells in the field. Any operator may use any gas storage well for gas injection or withdrawal purposes.

Rule 3 is a surface casing requirement rule which is identical to the present surface casing rule for the field.

Rule 4 provides for a maximum gas-oil ratio of 10,000 cubic feet per barrel.

The rules summarized above govern the underground storage of natural gas with emphasis on conservation.

A Unique Storage Problem in Texas

The Bacon Storage Reservoir in the Tri-Cities Field in east Texas presents a special problem to the storage of natural gas.

The unit agreement permits the operator to store gas indefinitely and to produce liquids from the Bacon not recoverable from primary production. In the unitization of the reservoir, there was one operator unwilling to join the unit. On his 89-acre lease is located a dual gasser completed from the Bacon and Travis Peak pays with a potential of approximately 900,000 cubic feet daily. The unit operator claims that this well could produce 85% of the zone's total storage capacity if allowed to produce 1,000,000 cubic feet daily for the 50-year life expectancy of the storage operation.

This presents a special problem in Texas since there is no compulsory unitization. A legal decision must, therefore, be made to decide whether an operator retains title to injected gas he bought and paid taxes on or whether the injected gas becomes subject to the law of capture.

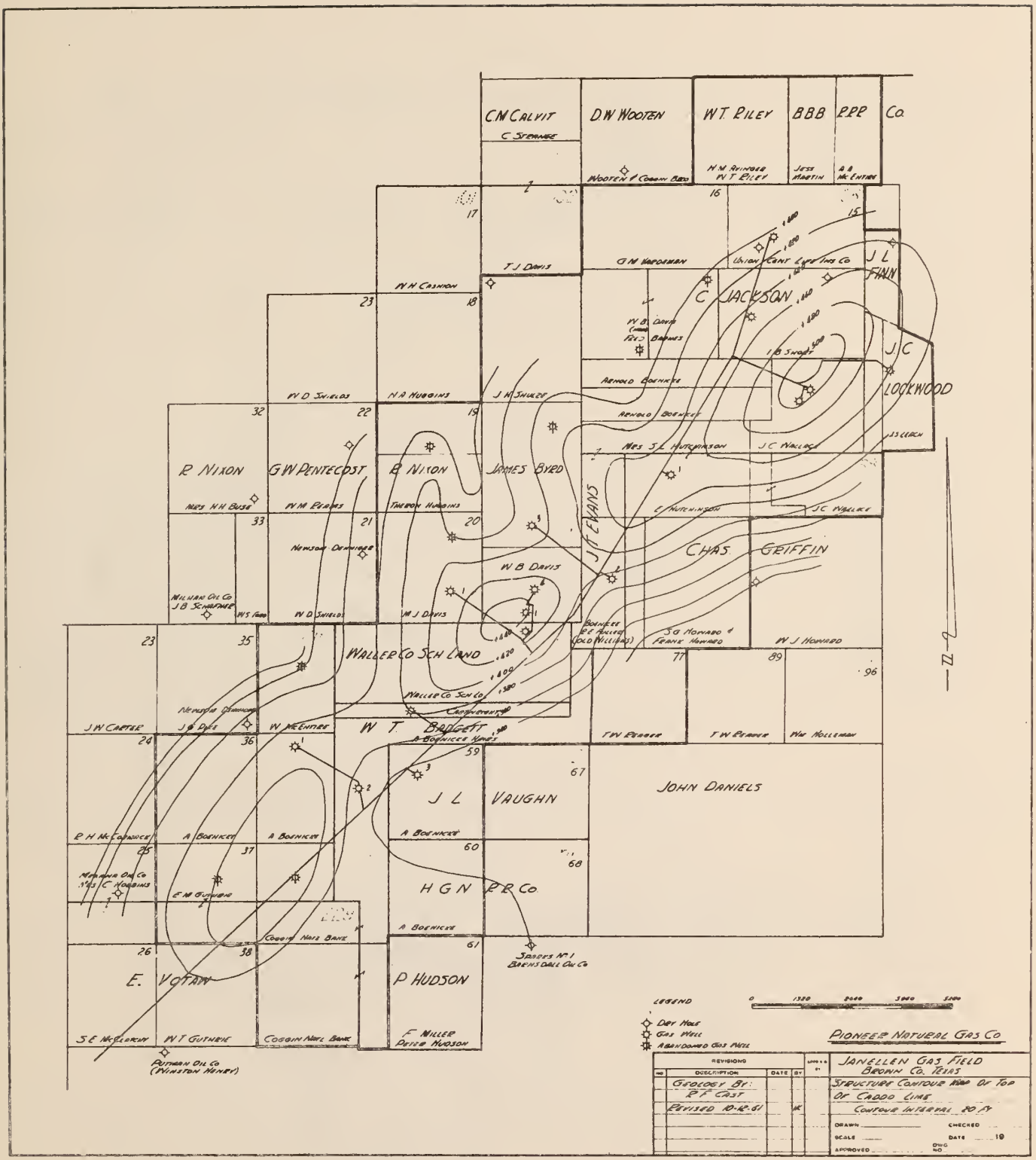

C.M. CALVIT
C STRANGE
D.W. WOOTEN
WOOTEN & COGGIN BROS
W.T. RILEY
H.M. AVINGER
W.T. RILEY
BBB
JESS MARTIN
RRR
A.A. McENTIRE
Co.
T.J. DAVIS
G.M. VARDEMAN
UNION CENT LIFE INS CO
J.L. FINN
W.H. CASHION
C. JACKSON
W.B. DAVIS
FRED BARNES
I.B. SHORT
J.C. LOCKWOOD
ARNOLD BOENICKE
W.D. SHIELDS
N.A. HUGGINS
J.H. SHULZE
MRS S.L. HUTCHINSON
J.C. WALLACE
R. NIXON
G.W. PENTECOST
R. NIXON
JAMES BYRD
MRS H.H. BUSE
W.M. REAMS
THERON HUGGINS
J.T. EVANS
E. HUTCHINSON
J.C. WALLACE
NEWSOM DENNIGER
CHAS. GRIFFIN
W.B. DAVIS
MILHAM OIL CO
J.B. SCHAFFNER
W.S. FORD
W.D. SHIELDS
M.J. DAVIS
BOENICKE
R.E. FULLER
(OLD WILLIAMS)
S.G. HOWARD &
FRANK HOWARD
W.J. HOWARD
WALLER CO SCH LAND
WALLER CO SCH LD
CARTWRIGHT
NEWSOM DENNIGER
J.W. CARTER
J.G. DIXE
W. McENTIRE
W.T. BADGETT
A. BOENICKE HEIRS
T.W. REAGER
T.W. REAGER
WM HOLLEMAN
J.L. VAUGHN
JOHN DANIELS
R.H. McCORMICK
A. BOENICKE
A. BOENICKE
A. BOENICKE
MEMPHIS OIL CO
MRS C. HOBBINS
E.M. GUTHRIE
H.G.N. RR Co.
A. BOENICKE
COGGIN NAT'L BANK
SPARKS No 1
BARNSDALL OIL CO
E. VOTAW
P. HUDSON
S.E. McCLATCHY
W.T. GUTHRIE
COGGIN NAT'L BANK
F. MILLER
PETER HUDSON
PUTMAN OIL CO
(WINSTON HENRY)
LEGEND
DRY HOLE
GAS WELL
ABANDONED GAS WELL
PIONEER NATURAL GAS CO
REVISIONS
NO
DESCRIPTION
DATE
BY
GEOLOGY BY:
R.F. CAST
REVISED 10-12-61
JANELLEN GAS FIELD
BROWN CO. TEXAS
STRUCTURE CONTOUR MAP OF TOP
OF CADDO LIME
CONTOUR INTERVAL 20 FT
DRAWN
CHECKED
SCALE
DATE 19
APPROVED
DWG NO

Figure 114.

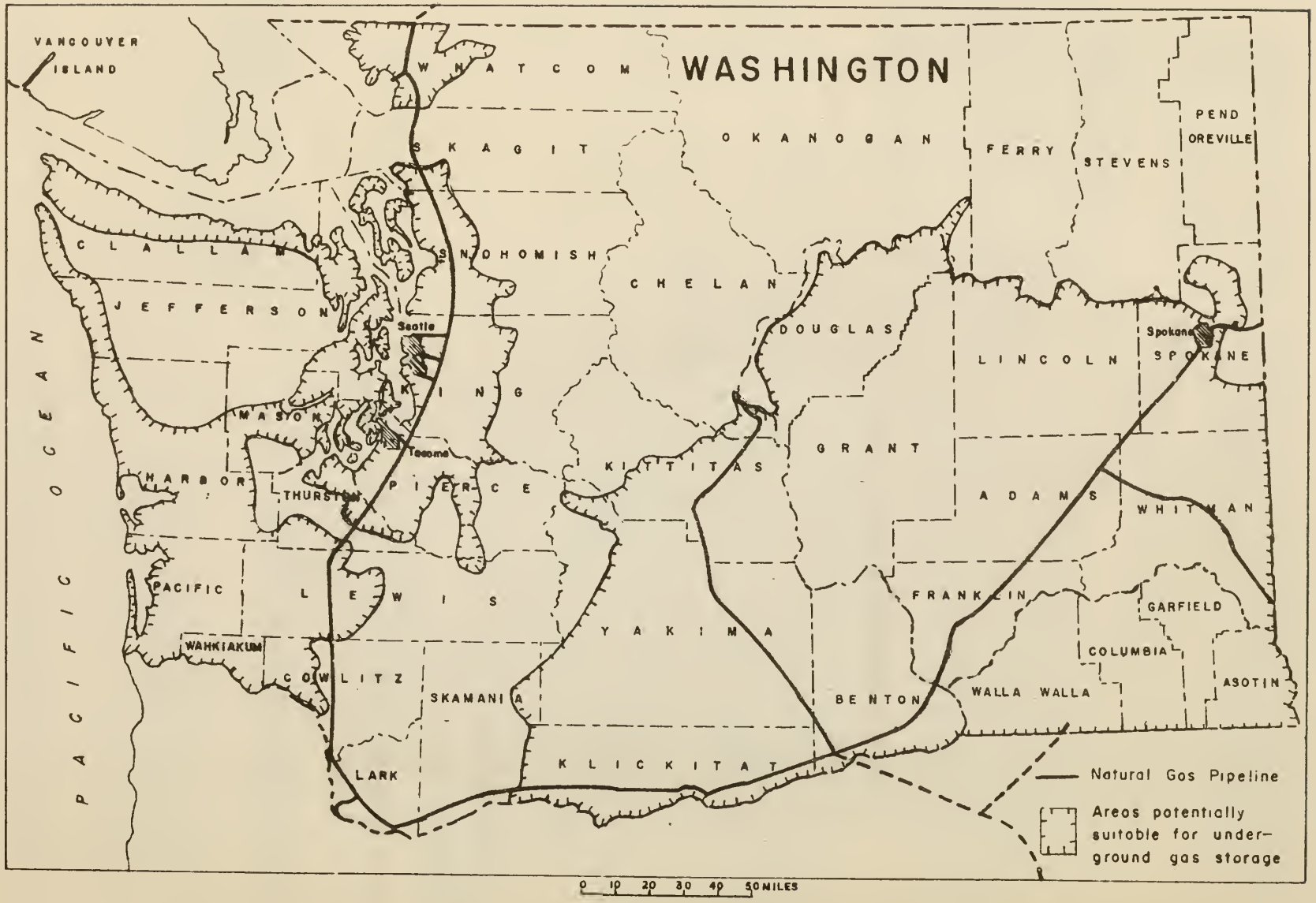

WASHINGTON
VANCOUVER ISLAND
PACIFIC OCEAN
WHATCOM
SKAGIT
OKANOGAN
FERRY
STEVENS
PEND OREVILLE
CLALLAM
SNOHOMISH
CHELAN
JEFFERSON
Seattle
DOUGLAS
LINCOLN
Spokane
SPOKANE
KING
MASON
Tacoma
GRANT
HARBOR
THURSTON
PIERCE
KITTITAS
ADAMS
WHITMAN
PACIFIC
LEWIS
FRANKLIN
GARFIELD
YAKIMA
WAHKIAKUM
COLUMBIA
COWLITZ
SKAMANIA
BENTON
WALLA WALLA
ASOTIN
KLICKITAT
LARK
Natural Gas Pipeline
Areas potentially suitable for underground gas storage
0 10 20 30 40 50 MILES

Figure 115.

Conclusions

Underground storage of natural gas benefits the public in many ways -- elimination of waste during off-demand periods, reduction of costs required to deliver gas to consumer, and the possibility of secondary recovery of crude oil.

Through the use of underground storage of natural gas, Texas provides a source of gas to be used during peak demand periods. Through the use of its seven underground storage projects, transmission lines in the vicinity of the storage reservoirs can be operated to near capacity the year around.

Acknowledgement of Maps and Other Data

Railroad Commission of Texas
Lone Star Gas Company
Pioneer Natural Gas Company.

WASHINGTON

Marshall T. Huntting, Supervisor
Division of Mines and Geology

Although the natural gas pipeline that supplies Washington is fed from both ends with state's market center being located in the middle, the sources of supply for gas at the ends are more than a thousand miles from Washington. Gas is fed from the Four Corners area in the southwestern United States and from the Dawson Creek area of British Columbia and Alberta, Canada. Because of the long distances from supply, the need for underground storage of gas in Washington near the centers of consumption is obvious.

A very small amount of gas was produced in the Rattlesnake Hills Field in eastern Washington from 1926 to 1941. This has been the only commercial gas production in Washington up to the present time. Good shows of gas have been encountered in wells drilled in Whatcom County, King County, Grays Harbor County, and other areas in western Washington. The accompanying map (figure 115) shows the outlines of areas that are underlain by rocks that may be suitable for use as underground gas reservoirs where structural conditions may be favorable.

The natural gas pipeline (also shown in figure 115), which was laid within the past ten years, has stimulated new interest in exploration for gas in Washington. It is anticipated that production will be found within a few years. However, until such production is established here, the need for underground storage is especially great, and even after production is established here, there will be continued need for storage in the area.

A deterring factor in the development of underground storage here has been the lack of depleted oil or gas reservoirs that could be used for storage. The old Rattlesnake Hills Reservoir is too far from the principal markets to be especially useful and it lies within the Reservation of the Hanford Atomic Works of the United States Atomic Energy Commission and therefore is not available for development. The uncertainties and hazards of developing reservoirs for storage of natural gas in sedimentary rock formations other than depleted oil or gas reservoirs have been such that no underground storage projects have been completed in Washington.

Some detailed seismic exploration to explore reservoir structure conditions has been completed in three areas -- in Spokane County, in Whatcom County, and in Lewis County. A well in the Lewis County area was drilled to a depth of 8,015 feet as a combined test of underground storage possibilities and test for oil and gas. Further exploration in this area is anticipated. It is quite possible, also, that additional work to develop underground storage will be done in Whatcom and Spokane Counties, as well as in other areas in Washington.

The areas shown in Western Washington (figure 115) as having possibilities for gas storage are underlaid by noncalcareous sedimentary rocks of Tertiary age. The area in eastern Washington shown in figure 115 as favorable for gas storage is underlaid by Miocene basalt. It is possible that in some areas in this rock where structural conditions are favorable, underground storage reservoirs might be developed. In general, the basalt flows are very porous and permeable. In places there are inter-basalt sedimentary beds which are impermeable and which could act as effective caprocks.

In western Washington, the possibilities of developing underground storage reservoirs in Tertiary sedimentary rocks are at least as good as the possibility of finding oil or gas production in these rocks. A considerable amount of effort and money are currently being invested in this search for oil and gas, and further underground gas storage exploration is anticipated.

No special laws to regulate natural gas storage operations are in effect in Washington. However, the exploration drilling for such projects is regulated by the Washington Oil and Gas Conservation Act (Laws of Washington, 1951, Chapter 146). The last two sessions of the Washington Legislature have considered legislation which would extend the power of eminent domain to underground gas storage companies. The need is obvious, but this legislation has not yet been enacted.

WEST VIRGINIA

Ping-fan Chen, Assistant Petroleum Geologist
West Virginia Geological and Economic Survey

Gas Production

The gas producing area in West Virginia is extensive, covering most of the northwestern half of the state besides some parts of the southeastern half. The detailed locations of these gas fields are shown on figure 116. No data are available on gas production in West Virginia from 1860 to 1884. Only values at points of consumption are available from 1885 to 1905, the total for that period being $43,679,412. From 1906 to 1959, some 10,106,751 millions of cubic feet of gas were produced in West Virginia, valued at points of consumption at about two billion dollars. In this, the highest producing state of eastern United States, the highest annual production was 308 billion cubic feet in 1917 (table 34). The present production is about 200 billion cubic feet annually. The production of gas, however, is very flexible and much influenced by the market.

Table 34 - Gas Production in West Virginia

Year	Gas (MMcf)	Year	Gas (MMcf)
1906	119,400	1933	100,653
1907	122,687	1934	109,161
1908	112,181	1935	115,772
1909	166,435	1936	138,076
1910	190,766	1937	149,084
1911	206,891	1938	134,342
1912	239,007	1939	159,226
1913	245,454	1940	188,751
1914	236,489	1941	207,681
1915	244,004	1942	235,000
1916	299,319	1943	252,000
1917	308,617	1944	213,000
1918	265,161	1945	192,049
1919	234,095	1946	203,489
1920	239,719	1947	218,460
1921	174,921	1948	221,130
1922	195,288	1949	181,310
1923	203,867	1950	197,210
1924	182,285	1951	184,000
1925	180,345	1952	166,470
1926	180,223	1953	174,190
1927	162,375	1954	171,380
1928	163,018	1955	183,170
1929	167,333	1956	210,000
1930	144,180	1957	189,000
1931	124,797	1958	197,250
1932	100,540	1959	205,000
		Total	10,106,751

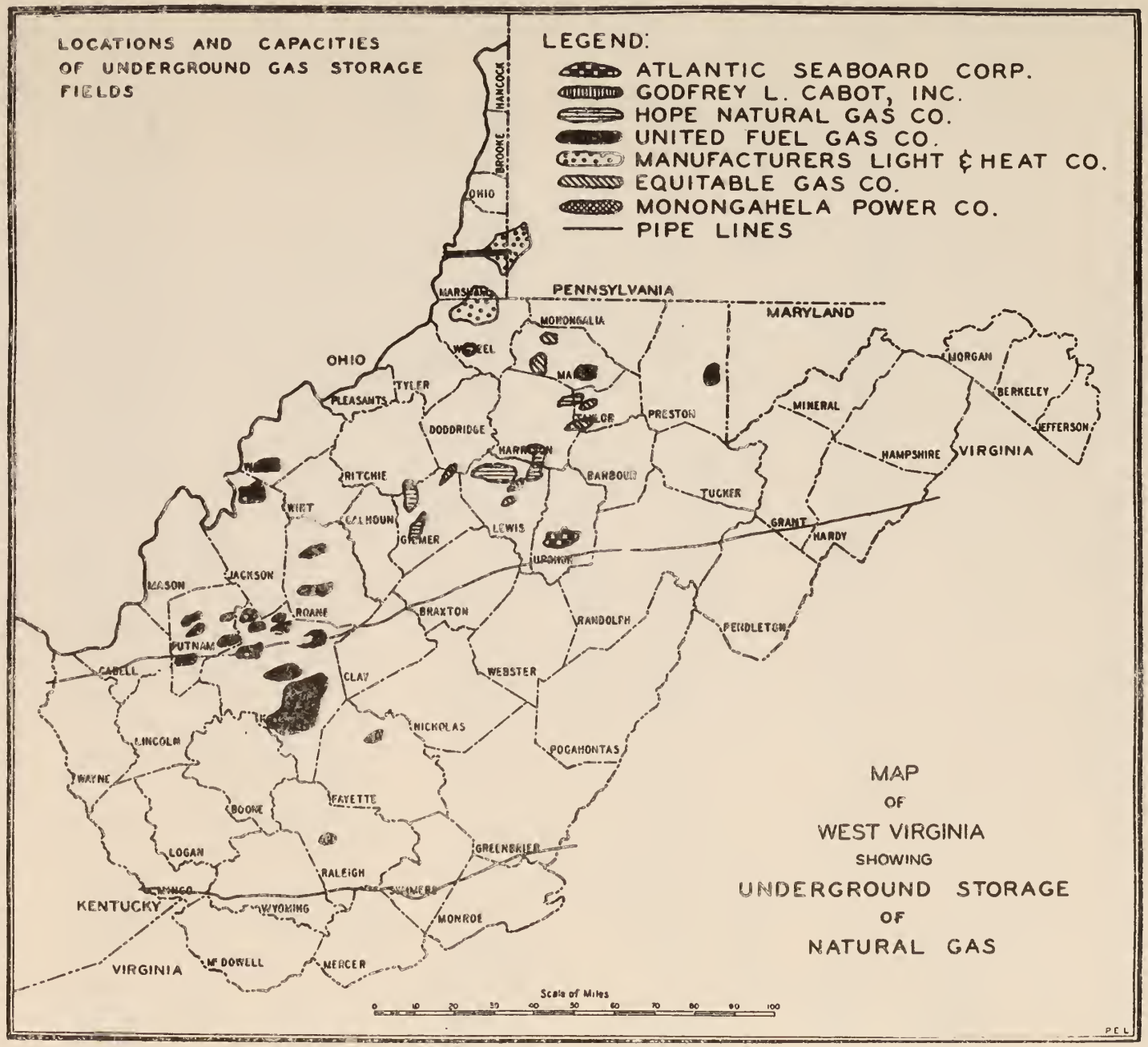

LOCATIONS AND CAPACITIES OF UNDERGROUND GAS STORAGE FIELDS
LEGEND:
ATLANTIC SEABOARD CORP.
GODFREY L. CABOT, INC.
HOPE NATURAL GAS CO.
UNITED FUEL GAS CO.
MANUFACTURERS LIGHT & HEAT CO.
EQUITABLE GAS CO.
MONONGAHELA POWER CO.
PIPE LINES
PENNSYLVANIA
MARYLAND
OHIO
VIRGINIA
KENTUCKY
HANCOCK
BROOKE
OHIO
MARSHALL
MONONGALIA
WETZEL
MARION
TYLER
PLEASANTS
DODDRIDGE
HARRISON
TAYLOR
PRESTON
MINERAL
MORGAN
BERKELEY
JEFFERSON
HAMPSHIRE
RITCHIE
BARBOUR
TUCKER
WIRT
CALHOUN
GILMER
LEWIS
UPSHUR
GRANT
HARDY
MASON
JACKSON
ROANE
BRAXTON
RANDOLPH
PENDLETON
PUTNAM
CABELL
CLAY
WEBSTER
NICHOLAS
POCAHONTAS
LINCOLN
WAYNE
BOONE
FAYETTE
GREENBRIER
LOGAN
RALEIGH
SUMMERS
MINGO
WYOMING
MONROE
McDOWELL
MERCER
MAP OF WEST VIRGINIA SHOWING UNDERGROUND STORAGE OF NATURAL GAS
Scale of Miles
0 10 20 30 40 50 60 70 80 90 100
PEL

Figure 116.

At the end of 1959, there were approximately 15,800 gas wells in West Virginia completed, of which some 20-inch, 24-inch, and 30-inch interstate gas lines are shown on the map. Certainly, Pittsburgh is the biggest gas market of the state.

Geology of West Virginia in Reference to Gas Storage

Stratigraphy

Precambrian - The small exposure of Catoctin greenstone in Jefferson County is the only exposure of Precambrian rock in West Virginia. The deep well near Parkersburg in the western part of West Virginia is the first of two wells to be drilled into the basement rock in the state, the other being in Mason County. The exposed Precambrian volcanic series may not be very widespread, but the metasediments encountered in this well may underlie the younger formations throughout West Virginia.

Cambrian - The outcropping Cambrian rocks in West Virginia are also limited, having been found in two narrow belts in Jefferson and Berkeley Counties only. Based on the surface and subsurface data, the Cambrian rocks consist of the following formations in ascending order:

Formations	Average Thickness In Feet
1. Weverton Formation - sandstone and conglomerate	500
2. Harper Formation - sandstone and shale	1,000
3. Antietam sandstone - sandstone and shale	500
4. Tomstown dolomite - dolomite	1,300
5. Waynesboro Formation - shale, siltstone, sandstone, limestone and dolomite	1,200
6. Elbrook Formation - limestone and dolomite	2,200
7. Conococheague Formation - limestone and dolomite	1,800

Ordovician - Although exposed Ordovician rocks are, like Cambrian, confined to the southeastern part of West Virginia, more information has been collected from wells. The Ordovician rocks, including surface and subsurface, consist of the following formations:

Formations	Average Thickness In Feet
1. Chepultepec limestone - limestone	400
2. Beekmantown limestone - limestone and dolomite	2,400
3. Chazy limestone - dolomite and limestone	650
4. Chambersburg limestone - limestone	500
5. Martinsburg shale - shale and sandstone	1,500
6. Oswego sandstone (Gray Medina) - sandstone	200
7. Juniata Formation (Red Medina) - sandstone	600

Silurian - Silurian rocks are fairly well known from the study of subsurface data of a good many wells in addition to study of the surface data from the narrow zones in the southeastern part of West Virginia. An unconformity is present between the Silurian and Ordovician in the state. Many divisions have been named for the great variety of Silurian rocks.

Formations	Average Thickness In Feet
1. Tuscarora sandstone - quartzite or quartzitic sandstone	150
2. Rose Hill Formation - shale and sandstone	400
3. Keefer sandstone - sandstone	330
4. Rochester shale and McKenzie Formation - shale, limestone, and dolomite	300

5. Williamsport sandstone - sandstone	25
6. Wills Creek Formation and Tonoloway limestone	700

Devonian - Devonian rocks have larger exposed areas in southeastern part of West Virginia than have any of the older rocks. Although the exposed Devonian rocks extend beneath the surface in the rest of the state, the formations recognized by surface study may not be identifiable in the wells. Because of rapid changes in facies formations of the same age, they may be of unlike lithology, and those of similar rock character may not be of the same age. Former workers have divided the Devonian rocks in West Virginia into the following units:

Formations or Groups	Average Thickness In Feet
1. Helderberg Group - limestone and shale	400
2. Oriskany (Ridgeley) sandstone - sandstone	100
3. Huntersville chert and Needmore shale - chert and shale	150
4. Marcellus shale - shale	300
5. Hamilton Formation - shale and sandstone	600
6. Harrell shale - shale	300
7. Brallier shale - shale and sandstone	2,000
8. Chemung Formation - sandstone and shale	1,500
9. Hampshire Formation - shale, siltstone and sandstone	1,500

Mississippian - Mississippian rocks outcrop in a wide zone in the southeastern part of West Virginia. They lie conformably on older Devonian rocks but underlie unconformably the younger Pennsylvanian formations.

Three divisions of Mississippian rocks have been named. They are:

Series	Average Thickness In Feet
1. Pocono Series - shale and sandstone	600
2. Greenbrier Series - limestone , sandstone and shale	200
3. Mauch Chunk Series - shale, sandstone and limestone	600

Two of these Mississippian divisions are much thicker in southeastern West Virginia where the Greenbrier reaches a thickness of at least 1,800 feet and the Mauch Chunk 3,500 feet.

Pennsylvania - The Pennsylvanian rocks cover the central belt of West Virginia. They consist of four subdivisions:

Series	Average Thickness In Feet
1. Pottsville Series - sandstone and shale	600 (3,800 in SE W. Va.)
2. Allegheny Series - sandstone and shale	200
3. Conemaugh Series - shale, sandstone and limestone	550
4. Monongahela Series - sandstone, shale and limestone	350

Permian - Covering the northwestern part of West Virginia, the Permian rocks, included in the Dunkard Series, are mainly shale and sandstone with maximum thickness of 1,200 feet.

Most productive gas reservoirs are sandstones and limestones of the Devonian and Mississippian Systems, though gas has been produced from Pennsylvanian, Silurian, and Ordovician rocks. The reservoir rocks or "sands" are listed as follows:

		Carroll
	Monongahela	Sewickley coal
		Pittsburgh coal
		Minshall
		Murphy
	Conemaugh	Moundsville
		Little Dunkard (1st Cow Run)
Pennsylvanian		Big Dunkard
		Burning Springs
	Allegheny	Gas Sands
		Cow Run
		Horseneck
	Pottsville	Salt Sands
		"Maxton"
	Mauch Chunk	Maxton
		Big Lime
Mississippian	Greenbrier	Keener
		Big Injun (in part)
		Big Injun (in part)
	Pocono	Squaw
		Weir
		Berea
		Gantz
		Fifty-Foot (Hundred-foot)
		Thirty-Foot
		Gordon Stray (Stray)
		Gordon
		Fourth
		Fifth
		Bayard (Bayard, Sixth)
		Elizabeth (Seventh)
		First Warren
		Burnside
		Tiona
		Speechley
		Balltown
		Riley
Devonian		Benson
		Elk
		Kane
		Childress
		"Brown shale"
		Huntersville
		Oriskany
	Cayugan	Newberg
Silurian	Niagaran	Lockport
		Big Six
	Medinan	"Clinton" (Tuscarora)

Structure

Three zones of structural conditions can be distinguished in West Virginia: the southeastern zone of tight folds, the central zone of gentle warping, and the northwestern zone of regional dip.

The zone of tight folds is in the northwestern part of the Folded Appalachians and consists of pre-Mississippian rocks. The central zone of gentle warping is in the southeastern part of the Appalachian Plateau which is separated from the Folded Appalachians by the Appalachian structural Front and includes Mississippian and Pennsylvanian rocks. The northwest regional dip zone, which also belongs to Appalachian Plateau, is covered by the Permian beds.

Gas is produced in the central gentle warping and northwest regional dip zones. The structure controls part of the traps of gas.

Gas Storage Projects

The first successful underground storage project was effected in Welland County, Ontario, Canada, in 1915. Following New York and Kentucky, storage in West Virginia began, probably before 1925. By 1936, the storage of gas of the state was no longer on a small scale and had attained a capacity of 868 million cubic feet during the previous year. After the completion of the pipelines from the southwest, gas storage projects increased rapidly in West Virginia between 1940 and 1950. Since then, they have continued to increase in number and importance. The capacity during the last few years is given as follows:

Years	Capacity In Mcf
1956	282,817,967
1957	304,874,000
1958	306,522,000

The increasing of the storage gas in West Virginia is about 10% annually. In 1959, ranking third in the states, West Virginia had a full capacity of 306,522,000 Mcf which is distributed among 39 storage fields of seven gas companies. The largest field is the Fink of Hope Natural Gas Company which can store 56,000,000 Mcf. The next largest are X-52A of the United Fuel Gas Company, Victory of Manufacturers Light and Heat Company, and Kennedy of Hope Natural Gas Company. The capacities of the last three fields are each over 30,000,000 Mcf. Statistics of the gas storage projects are shown in table 35.

Possibilities of Expansion

In West Virginia, more projects of underground gas storage will be developed in the next few years. The proposed storage areas are selected from the depleted oil and gas pools in the state.

Besides the use of depleted oil and gas reservoirs for gas storage, use of underground space left by the dissolving of rock salt in Franklin District, Marshall County, has been suggested.

At present, no other types of storage reservoirs have been employed in West Virginia. Certainly some of the depleted salt water aquifers can also be considered as possible gas storage reservoirs.

Regulations Affecting Storage Projects

To prevent the interference between underground gas storage and coal mines, the state passed the House Bill No. 428 (Gas Storage Bill) in 1955. The bill is explained in summary as follows:

1. It defines the reservoir protective area of the storage gas as all the area outside of and surrounding the storage boundary but within 2,000 feet thereof.

2. It requires filing of maps and data by persons operating or proposing to operate gas storage or coal mine. Many measures must be taken for protection wherever the underground gas storage is too close to an active coal mine. The claimant must file maps and data pertaining to area within certain distance of gas storage or coal mine.

Table 35 - Gas Storage Projects in West Virginia

Company Field or area County	Reservoir Rock	Type of Trap	Date	Capacities (Mcf)
I. Atlantic Seaboard Corp.				
1. X-56 - Upshur				9,000,000
II. Equitable Gas Co.				
1. Comet - Taylor	50-Ft.	Strat.	4-15-36	5,100,000
2. Drain - Doddridge	Big Injun	Strat.	10-20-44	410,000
3. Hayes - Marion				225,000
4. Logansport - Marion				3,000,000
5. Maple Lake - Taylor	Big Injun & 50-Ft.	Strat.		2,550,000
6. Rhodes - Lewis				10,475,000
7. Skin Creek - Lewis	Gordon	Strat.	3-4-36	1,520,000
III. Godfrey L. Cabot, Inc.				
1. Fayette Land Co. - Fayette				32,000
2. Heizer X-1 - Putnam				3,600,000
3. Raleigh - Raleigh				2,100,000
IV. Hope Natural Gas Co.				
1. Bridgeport - Harrison and Taylor	50-Ft.		May, 1932	9,500,000
2. Fink - Doddridge & Lewis	Berea			56,000,000
3. Kennedy - Harrison & Lewis				31,000,000
4. Newberne - Gilmer	Berea			5,000,000
5. Racket - Gilmer & Ritchie	Berea		1947	4,000,000
6. Crows Run - Wetzel				750,000
V. Manufacturers Light and Heat Co.				
1. Victory - Marshall & Wetzel	"Maxton"			35,000,000**
2. Majorsville - Marshall*	Salt			14,310,000
VI. Monongahela Power Co.				
1. Pitzer - Marion	SS in Allegheny	Strat.		1,000,000
VII. United Fuel Gas Co.				
1. X-1 - Putnam				1,900,000
2. X-2 - Kanawha	Oriskany			4,900,000
3. X-4 - Putnam	Greenbrier			4,200,000
4. X-6 - Kanawha	Oriskany			6,300,000
5. X-7 - Kanawha	Oriskany			1,500,000
6. X-8 - Kanawha				1,650,000
7. X-15A - Putnam	Greenbrier			1,750,000
8. X-15B - Kanawha				2,450,000
9. X-17 - Roane	Berea			2,800,000
10. X-19A - Roane	"Big Injun"			2,400,000
11. X-19B - Roane	"Big Injun"			2,400,000
12. X-49 - Putnam				1,800,000
13. X-52A - Kanawha	Oriskany			38,000,000
14. X-52B - Kanawha				9,200,000
15. X-52C - Kanawha				14,800,000
16. X-53 - Kanawha				60,000
17. X-54 - Kanawha				4,500,000
18. X-58 - Wood & Wirt	Oriskany			7,900,000
19. X-59 - Jackson	Oriskany			20,000,000
20. X-76 - Preston (under way)	Oriskany			
Total				306,522,000

**Marshall County capacity only.
* Field extends into Washington and Greene counties, Pennsylvania

3. It requires notification of both coal operator and storage operator when it is found that a coal mine and a storage reservoir are within 10,000 feet of each other.

4. It requires notice by persons operating coal mines who have knowledge that their mines are located above or within two thousand linear feet of a gas storage reservoir.

5. It defines the obligations of persons operating a storage reservoir when this underlies or is within two thousand feet (linear) of an active mine which is operating in a coal seam that extends over the storage reservoir protective area.

6. It requires inspection of facilities and records.

7. The bill prescribes penalties for violation of its regulations.

WISCONSIN

George F. Hanson, State Geologist
Geological and Natural History Survey

The geologic structure of Wisconsin is essentially simple.

The Precambrian basement complex forms a broad arch whose axis trends north-south, approximately through the middle of the state, and which plunges gently to the south. The basement is overlain by sediments of Paleozoic age. The Precambrian basement outcrops in the central and north central part of the state, and the Paleozoic sediments outcrop to the west, south, and east forming an arcuate pattern around the Precambrian shield. Regional dips are gentle, varying from some 10 to 50 feet per mile. The steepest dips are eastward towards the Lake Michigan Basin, and it is on the eastern border of the state where the sedimentary strata attain their greatest thickness. This may be as much as 3,300 feet in the vicinity of Milwaukee.

The geologic section is shown in table 36, and the generalized distribution of the formations is shown in figure 117.

It will be noted that dolomite and sandstone are the predominant lithologies. Although some formations may contain subordinate shale, only the Maquoketa is predominantly shale. Aquifer performance tests indicate that the formations below the Maquoketa, although differing in their water yields, act essentially as a single aquifer. Hence, it is inferred that any natural structure that might confine gas would have to be capped by the Maquoketa shale.

Wells drilled specifically as oil tests in Wisconsin are rare, but as the Cambrian strata constitute one of the principle aquifers they are penetrated by numerous water wells. No indications of oil or gas have been encountered, and the negligible oil and gas possibilities in Wisconsin have been discussed in an article of that title by W. H. Twenhofel (A. A. P. G. Bull. Vol. 7, No. 6, pp. 653-660, 1923).

The density of well spacing is not sufficient to eliminate the possibility of closure on the base of the Maquoketa, but, if present, this would have to be determined by geophysical methods. Saline waters occur beneath the Maquoketa in some areas, notably Sheboygan and Manitowoc Counties. These attain a maximum of about 10,500 ppm dissolved solids and appear to indicate a lack of down-dip flushing.

Summary

The possibility of underground storage of gas in Wisconsin is poor. No structures are known that would serve to confine gas. The Maquoketa shale appears the only formation that might serve as a caprock, but suitable structures, if present, would have to be determined by geophysical methods.

Table 36.—Geologic section for the State of Wisconsin

System	Stratigraphic unit	Thickness (feet)	Character
Quaternary 1/	Recent alluvium	0-100?	Sand, gravel, peat, muck, marl.
	Pleistocene deposits	0-500	Boulder clay, silt, sand, gravel.
Devonian	Milwaukee fm. 2/	110	Shale, dolomite, limestone
	Thiensville fm. 2/	50	
Silurian	Waubakee dolomite, Niagara dolomite 2/	300-825	White to gray dolomite, some coral reefs. Crevices and solution channels locally abundant.
Ordovician	Maquoketa shale	50-540	Dolomitic shale. Some beds of dolomite up to 40 feet thick.
	Galena dolomite, Decorah fm., Platteville limestone 2/	200-350	Dolomite and limestone. Some shale (Decorah). Sandy at base.
	St. Peter sandstone	0-330 (Missing in places)	Sandstone, fine to medium grained, white to light gray to pink, dolomitic in places, cross-bedded. Red shale near base in some places.
	Prairie du Chien group (Includes Shakopee dolomite and Oneota dolomite.)	0-200 (Missing in places)	Dolomite. Sandy in some zones.
Cambrian	Trempealeau fm., Franconia sandstone, Galesville sandstone, Eau Claire sandstone, Mount Simon sandstone 2/	0-1000+	Fine to coarse grained sandstone, dolomitic, some shale and dolomite beds. Eau Claire and Franconia often shaly.
Precambrian	3/		Sandstone, quartzite, slate, granite, and other crystalline rocks.

1/ Not shown on map of bedrock geology.
2/ Not separated on map of bedrock geology.
3/ Shown by principal lithology on map of bedrock geology.

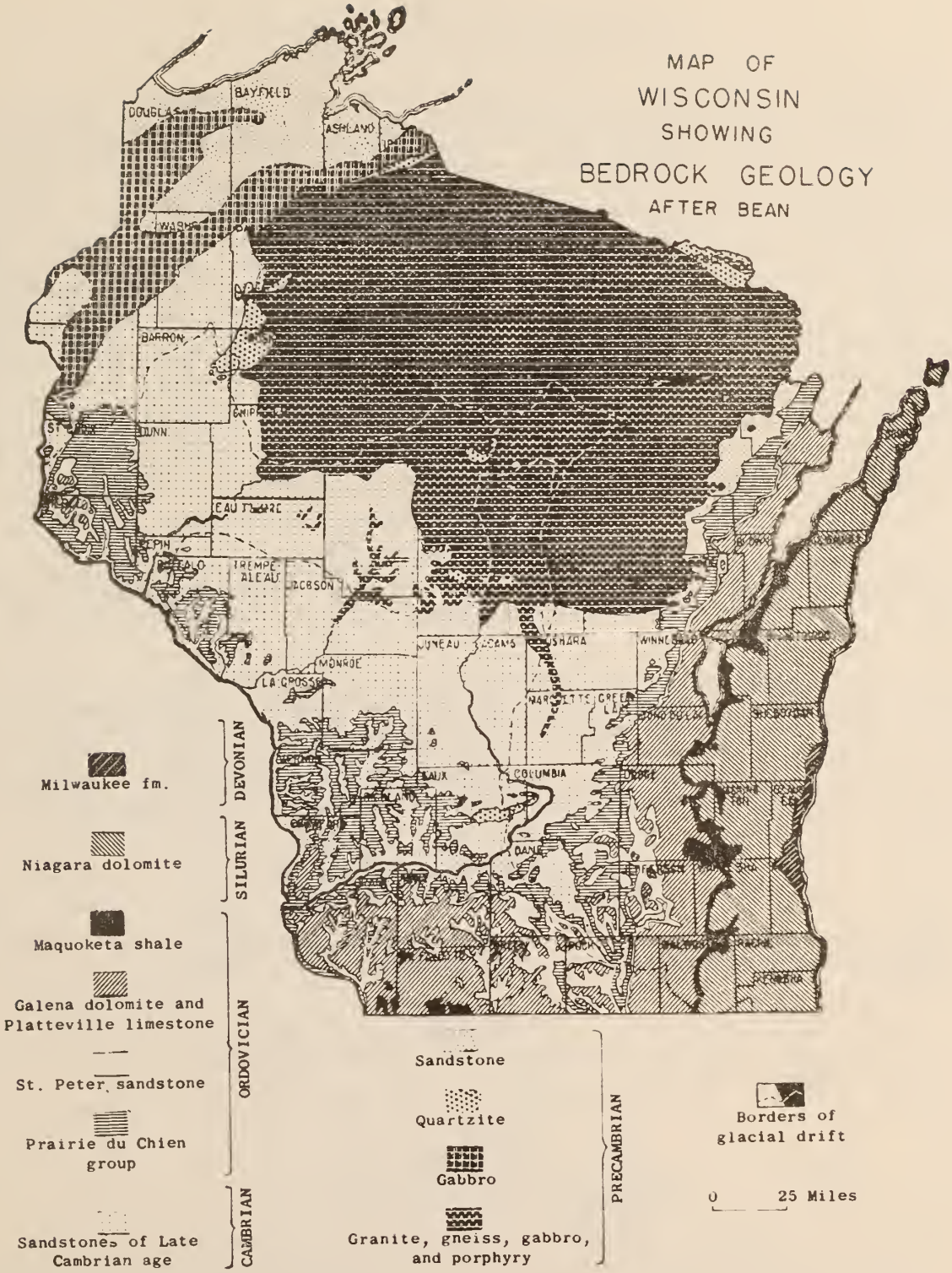

MAP OF
WISCONSIN
SHOWING
BEDROCK GEOLOGY
AFTER BEAN
BAYFIELD
DOUGLAS
ASHLAND
BARRON
DUNN
EAU CLAIRE
TREMPE-ALEAU
JACKSON
MONROE
LA CROSSE
JUNEAU
ADAMS
WAUSHARA
WINNEBAGO
COLUMBIA
DANE
Milwaukee fm.
Niagara dolomite
Maquoketa shale
Galena dolomite and Platteville limestone
St. Peter sandstone
Prairie du Chien group
Sandstones of Late Cambrian age
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
Sandstone
Quartzite
Gabbro
Granite, gneiss, gabbro, and porphyry
PRECAMBRIAN
Borders of glacial drift
0 25 Miles

Figure 117.

WYOMING

E. A. Swedenborg, State Mineral Supervisor
Oil and Gas Conservation Commission

The State of Wyoming has many nearly exhausted fields in which the reservoirs could be used for storage of natural gas. One utility is presently taking advantage of a nearly exhausted producing zone in the Billy Creek Field, Johnson County, Wyoming, in storage of gas. The Northwest State Utilities Company serves the towns of Buffalo and Sheridan, Wyoming. Originally the source of gas for these two municipalities was the Billy Creek Field. After a few years, as the source of supply for the above mentioned municipalities, the Billy Creek Gas Reservoir had insufficient pressures and gas reserve to meet the peak loads during the severe winters. A pipeline was then laid from the Casper area to the Billy Creek Field, a distance of approximately 96 miles. This line connected to the utility serving Casper, Wyoming, and, with its ample reserves, it was in a position to sell gas to the utility serving Buffalo and Sheridan, Wyoming. Since making this connection, gas has been used in the summertime, during light demands at Buffalo and Sheridan, for recharging the gas reservoir in the Billy Creek Field. The reservoir each summer has been charged up to its original pressures, and by this type of storage the needs of Buffalo and Sheridan have been successfully met during high peak demands during winter months. There are a number of other fields that could be similarly used should an occasion arise for need of storage space for gas. There has been consideration in some areas to the use of an oil reservoir for storage of gas, at the same time utilizing the gas for pressure maintenance of the oil reservoir. The injected gas would be credited and realized from the produced gas for ultimate utility use.

Figure 118 is a map of the State of Wyoming, showing the storage gas fields, pipelines, etc.

The present use of gas storage is indicated on figure 118 by a solid circle around the Billy Creek Field, previously mentioned as a field now in use for storage of gas. Fields which could be used for gas storage either in an exhausted or nearly exhausted gas reservoir or in a nearly depleted oil reservoir are enclosed by a broken circle.

With the completion of the Northwest Pipeline to outlets in Oregon and Washington, the exportation of natural gas from the State of Wyoming has rapidly increased. Some gas has been exported for a number of years to Salt Lake City, Utah, and to points in Nebraska, but it was not until the outlet afforded by the Northwest Pipeline that a real impetus was given to gas exploration in the southwestern part of the state. Wyoming has produced and sold gas for domestic and commercial use in the amount of 1,022,000,000 Mcf up to and including December, 1959. The production at the present time averages approximately 514,000,000 cubic feet per day.

Stratigraphy and Structural Geology of Wyoming in Reference to Gas Storage

The reservoir used and the reservoirs suggested as possible storage reservoirs, outlined on figure 118, range in age from Upper Cretaceous through Pennsylvanian.

Conclusions

Ample storage capacities for any prospective storage needs are available in Wyoming by use of depleted or semi-depleted reservoirs.

NEW MEXICO

Robert A. Bieberman
Bureau of Mines and Mineral Resources

New Mexico ranks third in the production of natural gas in the United States. During 1960, some 818,445,179 Mcf of gas was produced in the state. The San Juan Basin area in northwestern New Mexico accounted for 372,550,057 Mcf, and the Permian Basin area of southeastern New Mexico accounted for the remaining 445,894,222 Mcf. Approximately 3/4 of the total gas production was transported to markets outside of New Mexico.

New Mexico has two discontinued and two active gas storage projects. The discontinued projects are the Barker Dome project in San Juan County and the Vandagriff project in Eddy County. Withdrawals

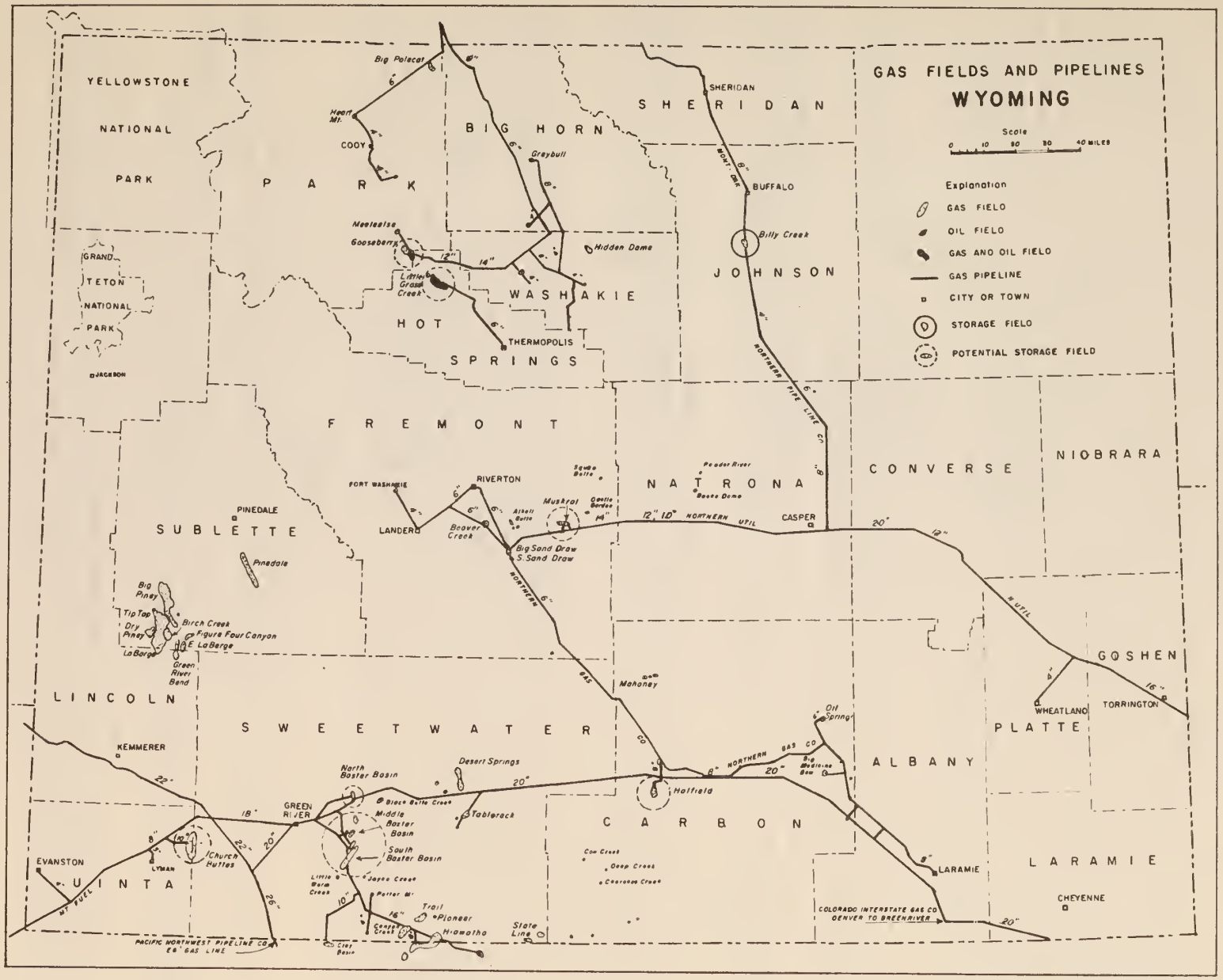

GAS FIELDS AND PIPELINES
WYOMING
Scale
0 10 20 30 40 MILES
Explanation
GAS FIELD
OIL FIELD
GAS AND OIL FIELD
GAS PIPELINE
CITY OR TOWN
STORAGE FIELD
POTENTIAL STORAGE FIELD
YELLOWSTONE NATIONAL PARK
GRAND TETON NATIONAL PARK
JACKSON
PARK
BIG HORN
SHERIDAN
JOHNSON
WASHAKIE
HOT SPRINGS
FREMONT
NATRONA
CONVERSE
NIOBRARA
SUBLETTE
LINCOLN
SWEETWATER
CARBON
ALBANY
PLATTE
GOSHEN
LARAMIE
UINTA
SHERIDAN
BUFFALO
Billy Creek
Big Polecat
Heart Mt.
COOY
Greybull
Meeteetse
Gooseberry
Little Grass Creek
Hidden Dome
THERMOPOLIS
FORT WASHAKIE
RIVERTON
LANDER
Beaver Creek
Muskrat
Big Sand Draw
S. Sand Draw
Powder River
Boone Dome
CASPER
PINEDALE
Pinedale
Big Piney
Tip Top
Dry Piney
Birch Creek
Figure Four Canyon
E. LaBarge
LaBarge
Green River Bend
KEMMERER
EVANSTON
LYMAN
Church Buttes
GREEN RIVER
North Baxter Basin
Middle Baxter Basin
South Baxter Basin
Desert Springs
Tablerock
Mahoney
Halfield
Oil Springs
Big Medicine Bow
LARAMIE
CHEYENNE
WHEATLAND
TORRINGTON
Trail
Pioneer
Hiawatha
State Line
Cow Creek
Deep Creek
Charcoal Creek
NORTHERN PIPE LINE CO
NORTHERN UTIL
NORTHERN GAS CO
N UTIL
MONT. DAK
MT FUEL
PACIFIC NORTHWEST PIPELINE CO 26" GAS LINE
COLORADO INTERSTATE GAS CO DENVER TO GREENRIVER

Figure 118.

of gas are still being made from these projects. The active storage projects are the Keyes project in Eddy County and the Rhodes project in Lea County (see figure 119).

Barker Dome Project

The Barker Dome project, now discontinued, was started by Southern Union Gas Company in 1947. Barker Dome is an asymmetrical dome located on the west rim of the San Juan Basin. Sweet gas was discovered in the Dakota (Cretaceous) Formation at a depth of 2,500 feet in 1925, and sour gas was found in the Paradox (Pennsylvanian) Formation at a depth of 9,000 feet in 1945. A purification plant was constructed to process the sour gas, and in 1947 the nearly depleted Dakota reservoir was converted to storage for excess gas from the outlet of the purification plant. This permitted the purification plant to be kept loaded without regard to seasonal demand. By 1958, the market demand for San Juan Basin gas had increased to the point where it was no longer necessary to store gas during periods of low demand. Consequently, no gas has been injected into the Barker Dome project since 1958. The operator does not anticipate placing any additional gas in storage. The stored gas will be withdrawn, as needed, until the storage reservoir is depleted. 365,632 Mcf was withdrawn during 1959, and the balance in storage on January 1, 1960, was 599,658 Mcf.

Vandagriff and Keyes Projects

The Vandagriff and Keyes storage projects are located five miles east of Artesia in Eddy County. Both projects are located within the horizontal limits of the Red Lake Field.

The Red Lake Field is located on a long east-west trending structural high. Differential porosity and other depositional factors play an important part in controlling accumulation. Oil and gas production is obtained from the Yates, Seven Rivers, Queen, Grayburg, and San Adres formations, all of Permian age.

The Vandagriff and Keyes projects are adjacent to one another, and both utilize the Queen sand, a depleted gas reservoir, as a storage reservoir. They are considered to be two separate projects since there appears to be a permeability barrier between them. The Queen sand under the Vandagriff project is hard and tight, while under the Keyes project there is good permeability. The pressures do not equalize when all wells are shut in.

The Southern Union Gas Company began the storage of gas in this area in 1942. During 1941 and 1942, there was a tremendous increase in demand for natural gas in the Roswell-Artesia-Carlsbad area. To meet this demand, the nearly depleted Keyes Gas Pool was converted to storage. This storage project placed additional supplies of natural gas near the points of consumption and also made it possible to utilize the full capacity of the transmission lines from Lea County during times of low seasonal demand. During 1959, the most recent year for which figures are available, 126,153 Mcf was injected into and 36,545 Mcf was withdrawn from the Keyes project. The balance in storage on January 1, 1960, was 1,138,878 Mcf. No gas has been injected into the Vandagriff project since 1951, and it is anticipated that the project will be depleted and abandoned in the near future. The balance in storage on January 1, 1960, was 387,214 Mcf.

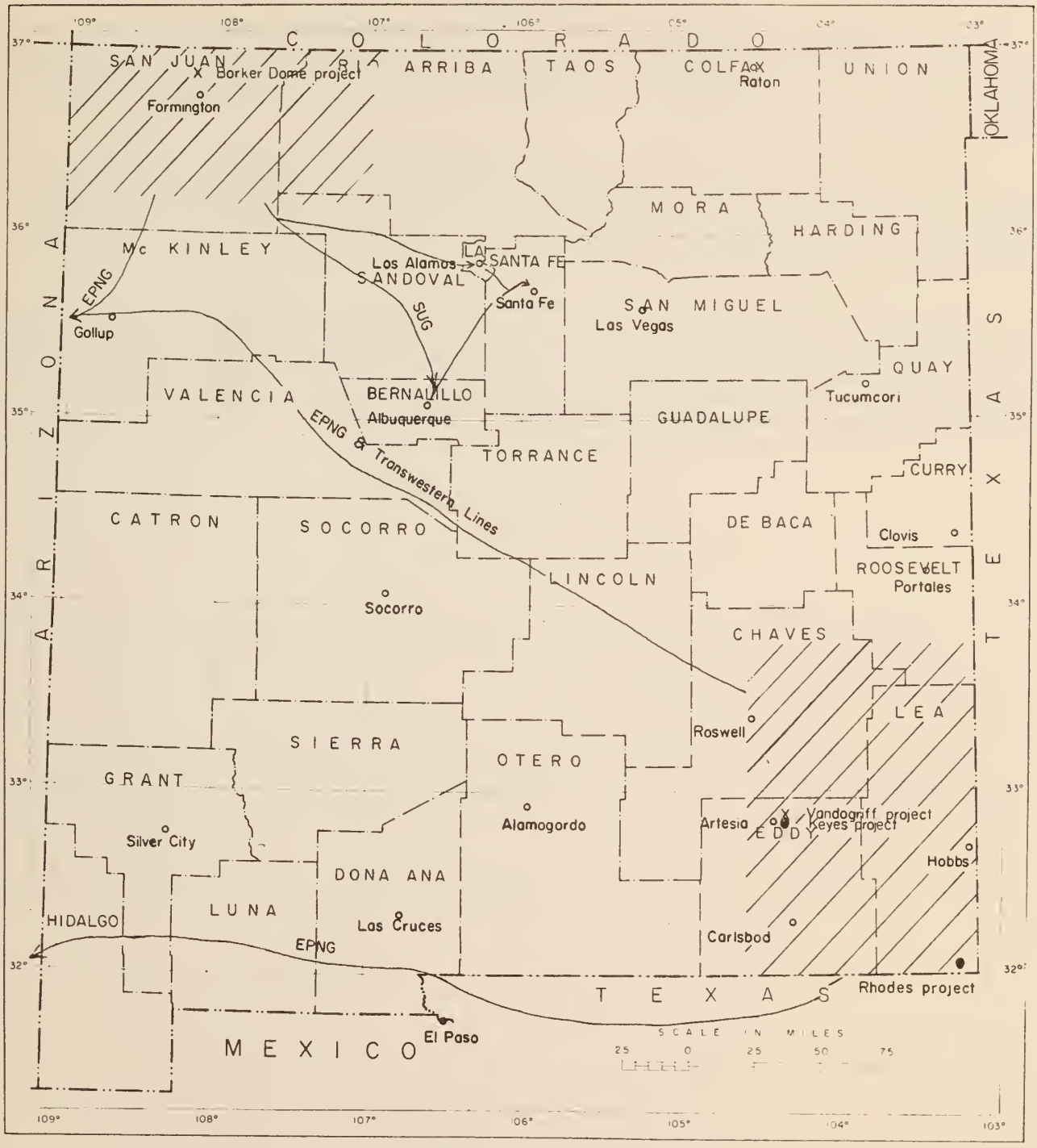
Rhodes Project

The Rhodes storage project is operated by the El Paso Natural Gas Company in the southern part of Lea County, New Mexico. The project utilizes the northern gas producing portion of the Rhodes Field.

The Rhodes Field appears to be a northwest trending anticline. However, lithologic changes control the reservoir on the east and to the north. Oil is produced in the southern portion and gas in the northern portion of the field from the Yates (Permian) Formation at a depth of about 3,200 feet.

The project was started in 1945 to store waste gas that would have been flared during light load periods. The project also created an additional supply of gas for use during periods of peak demand. The input gas is obtained from El Paso's Jal #1 extraction plant. During 1959, some 4,970,107 Mcf of gas was injected into and 7,191,896 Mcf was withdrawn from the project. The volume in storage on January 1, 1960, was 12,576,703 Mcf.

MAP OF NEW MEXICO SHOWING AREAS OF NATURAL GAS PRODUCTION, MAJOR GAS PIPELINES, AND GAS STORAGE PROJECTS.



EXPLANATION

X	Abandoned storage projects	●	Active storage project	SUG	Southern Union Gas Co
////	Gas producing area	——	Gas pipeline	EPNG	El Paso Natural Gas Co.

Figure 119

Future Storage

With one exception, there appears to be no great need for new storage projects in New Mexico for the purpose of placing additional supplies of gas near the points of consumption. The bulk of the gas consumed in New Mexico is consumed within the producing areas themselves. The remainder of the state is adequately served by pipeline at the present time, and no great increase in gas requirements is expected in the near future.

The one exception is the Albuquerque area. This is the largest consuming area outside of the producing areas and requires twice as much gas during the winter months as it does during the summer months. This uneven demand requires the maintainance of a much larger gathering and transmission system than would be needed if storage in the area were available. However, no structure suitable for the storage of gas has been found in the area.

At the present time, gas storage projects in New Mexico are most needed to provide for gas which might otherwise be vented or flared. During 1960, approximately 290,000,000 Mcf, or 35% of the total gas production in New Mexico was casinghead gas. The establishment of storage facilities for excess processed casinghead gas is certainly a wise conservation practice. The most logical sites for such storage facilities are within the producing areas themselves. Depleted or nearly depleted oil and or gas reservoirs offer the most economical storage facilities.

REPORTS FROM OTHER STATES

Brief statements on the underground storage of natural gas were received from the following six states:

Connecticut - The possibilities are nil, due to unfavorable geology.

Idaho - There is no natural gas production in the state; consequently, there has been no opportunity or need for underground storage.

Maine - Natural gas is not used in the state and consequently it is not stored here.

Tennessee - Three small gas pools have accounted for the gas production in the state. Underground storage of natural gas has not been attempted.

Utah - Mountain Fuel Supply Company has drilled five gas storage project and observation wells in Summit County. No additional information is available.

Virginia - To our knowledge, there are no underground storage installations for natural gas in the state.

The following four states did not submit reports: California, Nebraska, New Jersey and Vermont.

The states of Alaska and Hawaii were not involved in the study.

PAPERS PRESENTED DURING STUDY

Supplementing the material in this report are five excellent papers pertaining to underground gas storage which were given at the Interstate Oil Compact Commission meetings during this study.

At the June, 1959, meeting in New Orleans, William R. Clark, Natural Gas Storage of Illinois, presented a paper entitled, "The Geology of the Herscher Gas Storage Field, Kankakee County, Illinois."

Three papers were presented at the June, 1961, meeting in Houston: R. D. Grimm, Northern Natural Gas Company, "Underground Gas Storage in Aquifers;" Raymond L. Nace, U. S. Geological Survey, "Underground Storage of Radioactive Wastes;" and H. E. Schwalm, Northern Illinois Gas Company, "Water-Wall Storage."

The fifth paper was given at the December, 1961, meeting in Denver by Douglas Ball, Ball Associates, "The Leyden Coal Mine -- Its Use for Gas Storage."

Interstate Oil Compact